THESIS/
REPORTS
ULLIMAN,
J.J.

College of Forestry, Wildlife and Range Sciences

REMOTE SENSING FOR DETECTING TIME TRENDS
IN BOTTOM SEDIMENTS IN THE
SOUTH FORK OF THE SALMON RIVER

by

Dr. Joseph J. Ulliman, Professor

Harnek Singh, Graduate Assistant

College of Forestry, Wildlife and
Range Sciences, University of Idaho

Final Report to: USDA Forest Service,
Intermountain Forest and Range Experiment
Station, Contract 12-11-204-11, Supp.#107

December 1981

Forest, Wildlife and Range Experiment Station

University of Idaho

REMOTE SENSING FOR DETECTING TIME TRENDS IN BOTTOM SEDIMENTS IN THE SOUTH FORK OF THE SALMON RIVER

by

Dr. Joseph J. Ulliman, Professor

Harnek Singh, Graduate Assistant

College of Forestry, Wildlife and
Range Sciences, University of Idaho

Final Report to: USDA Forest Service,
Intermountain Forest and Range Experiment
Station, Contract 12-11-204-11, Supp.#107

December 1981

REMOTE SENSING FOR DETECTING TIME TRENDS IN BOTTOM SEDIMENTS IN THE SOUTH FORK OF THE SALMON RIVER

by

Dr. Joseph J. Ulliman, Professor
Harnek Singh, Graduate Assistant
College of Forestry, Wildlife
and Range Sciences
University of Idaho

December 1981

Final Report to:

USDA Forest Service
Intermountain Forest and Range
Experiment Station
Contract 12-11-204-11, Supp. #107

TABLE OF CONTENTS

	Page
Table of Contents	i
List of Tables	iv
List of Figures	vi
Acknowledgments	x
Abstract	xi
1.0 Introduction	1
1.1 Background	1
1.2 Objectives	7
1.3 Experimental Design	8
2.0 Methods and Procedures	10
2.1 Study Area	10
2.2 Acquisition of Ground Data	12
2.3 Aerial Photography	12
2.4 Determination of Tilt	13
2.5 Interpretation of Bottom Sediments	14
2.5.1 Dichotomous interpretation key and interpretation procedure	14
2.5.2 Particle size on negative scale (1:4000 scale)	17
2.5.3 Interpretation of sediments on small scale airphotos	17
2.6 Area Determination of Sediments	18
2.7 Determination of Riverbed Elevations and Contours	18
2.8 Statistical Analysis	20
2.9 Computer-Aided Maps for Depicting Time Trends	20
3.0 Results	24
3.1 Time Trends	25
3.1.1 Krassel Hole reach	25
3.1.2 Oxbow reach	25
3.1.3 Poverty reach	25
3.2 Comparison Between Ground Data and Airphoto Data	42
3.3 Riverbed Elevation and Contours	46
3.3.1 Cross-section profiles	50

Page

3.4 Statistical Analysis. 50

3.4.1 All three reaches 50
3.4.2 Eight cross-sections. 61
3.4.3 Ten transects based on Boise data 61

3.5 Modified Design 65

3.5.1 Statistical analysis of airphoto data 66
3.5.2 Statistical analysis of ground data versus airphoto data 66
3.5.3 Test of normality 70

3.6 Interpretation of Computer-Aided Maps 71

3.6.1 Krassel Hole reach computer maps with airphoto data 76

3.6.1.1 Krassel Hole reach map with sand distribution 76
3.6.1.2 Krassel Hole reach map with gravel distribution 78
3.6.1.3 Krassel Hole reach map with rubble distribution 78
3.6.1.4 Krassel Hole reach map with boulder distribution. 81

3.6.2 Krassel Hole reach computer maps with ground data 81

3.6.2.1 Krassel Hole reach computer map with sand distribution. 81
3.6.2.2 Krassel Hole reach computer map with gravel distribution. 84
3.6.2.3 Krasel Hole reach map with rubble distribution 86
3.6.2.4 Krassel Hole reach map with boulder distribution. 86

3.6.3 Poverty reach computer produced maps using airphoto data 86

3.6.3.1 Poverty reach computer map with sand distribution 86
3.6.3.2 Poverty reach computer map with gravel distribution 90
3.6.3.3 Poverty reach computer map with rubble distribution 90
3.6.3.4 Poverty reach computer map with boulder distribution. 93

3.6.4 Poverty reach computer maps from ground data. . . 93

Page

3.6.4.1 Poverty reach computer map with sand distribution. 93
3.6.4.2 Poverty reach computer map with gravel distribution. 96
3.6.4.3 Poverty reach computer map with rubble distribution. 96
3.6.4.4 Poverty reach computer map with boulder distribution 99

3.7 Comparison Between Large Scale and Small Scale Airphotos. . 99
3.8 Estimation of Accuracy of the Photo-Interpreted Information 101
3.9 Summary of Time and Cost. 104

4.0 Significance of Results. 106

5.0 Discussion 108

6.0 Conclusions and Recommendations. 112

7.0 Problems Encountered 113

8.0 Literature Cited and Other Useful References 115

9.0 Appendix 1. Modified Model Data 123

10.0 Appendix 2. Small Scale Airphoto Maps 127

LIST OF TABLES

Table No.	Title	Page
1	Existing aerial photography of the study area.	13
2	Estimates of tilt in the photographs	13
3	Parallax measurements of one point on each stereo pair.	19
4	Area (m^2) and percentage of sediments at Krassel Hole, Oxbow and Poverty reach from 1954, 1972, 1976, and 1979 aerial photos	38
5	Procedure for computing percentage of sediments from the planimetric map.	45
6	Percentage comparison of sediments, airphoto versus ground data for the year 1979 for Krassel Hole, Poverty reach and Oxbow reach.	47
7	Means, standard deviation, and other statistics for Table 6 data	47
8	Elevations from aerial photos and ground data for 1979 at the eight cross-sections (McCall data)	48
9	Analysis of variance from airphoto data for 1965, 1972, 1976, and 1979 for Krassel Hole, Poverty and Oxbow reaches.	60
10	Analysis of variance on airphoto data from the eight cross-sections of the three reaches from 1965 to 1979	62
11	Comparison between ground and airphoto data, means and standard deviations of 10 transects of Boise data	67
12	Analysis of variance for Krassel Hole transects from airphoto data, 1965 to 1979 (modified design) . . .	68
13	Analysis of variance for Poverty reach transects from airphoto data, 1965 to 1979 (modified design) . . .	69
14	Comparison of means and standard deviations (in percent) (modified model).	70
15	Analysis of variance for ground data 1972, 1976, and 1979 Krassel Hole transects.	72

Table No.	Title	Page
16	Analysis of variance for airphoto data, 1972, 1976, and 1979 Krassel Hole transects.	73
17	Analysis of variance for ground data, 1972, 1976, and 1979 Poverty transects	74
18	Analysis of variance for airphoto data, 1972, 1976, and 1979 Poverty transects	75
19	Comparison between large scale and small scale sediments for 1965 and 1972.	99
20	The accuracy of interpreted airphoto data computed with respect to Boise ground data and McCall ground data separately.	102
21	Mean percentages of sediment types for all data types for 1979	103
22	Summary of the cost ($) and time spent in producing planimetric maps depicting river bottom sediment types .	105

Appendix

1	1965 sediment percentages at 10 transects (modified model)	123
2	1972 sediment percentages at 10 transects (modified model)	124
3	1976 sediment percentages at 10 transects (modified model)	125
4	1979 sediment percentages at 10 transects (modified model)	126

LIST OF FIGURES

Figure No.	Title	Page
1	Experimental design of the study	9
2	Dichotomous interpretation key for riverbed sediments in a mountain stream	15
3	Planimetric map of 1965 riverbed sediments at Krassel Hole reach	26
4	Planimetric map of 1972 riverbed sediments at Krassel Hole reach	27
5	Planimetric map of 1976 riverbed sediments at Krassel Hole reach	28
6	Planimetric map of 1979 riverbed sediments at Krassel Hole reach	29
7	Planimetric map of 1965 riverbed sediments at Oxbow reach.	30
8	Planimetric map of 1972 riverbed sediments at Oxbow reach.	31
9	Planimetric map of 1976 riverbed sediments at Oxbow reach.	32
10	Planimetric map of 1979 riverbed sediments at Oxbow reach.	33
11	Planimetric map of 1965 riverbed sediments at Poverty reach.	34
12	Planimetric map of 1972 riverbed sediments at Poverty reach.	35
13	Planimetric map of 1976 riverbed sediments at Poverty reach.	36
14	Planimetric map of 1979 riverbed sediments at Poverty reach.	37
15	Time trend curves for Krassel Hole, 1946 to 1979	39
16	Time trend curves for Oxbow reach, 1965 to 1979.	40
17	Time trend curves for Poverty reach, 1965 to 1979.	41

Figure No.	Title	Page
18	A portion of Krassel Hole #2 cross-section from the 1979 planimetric map	44
19	Krassel Hole reach contour map based on heights measured from aerial photographs of 1979	51
20	Ground elevations versus aerial photo elevations at Krassel Hole #2 cross-section.	52
21	Ground elevations versus aerial photo elevations at Krassel Hole #3 cross-section.	53
22	Ground elevations versus aerial photo elevations at Upper Oxbow cross-section.	54
23	Ground elevations versus aerial photo elevations at Lower Oxbow cross-section.	55
24	Ground elevations versus aerial photo elevations at Oxbow Camp Creek cross-section	56
25	Ground elevations versus aerial photo elevations at Upper Poverty cross-section.	57
26	Ground elevations versus aerial photo elevations at Poverty cross-section.	58
27	Ground elevations versus aerial photo elevations at Lower Poverty cross-section.	59
28	Transects at Krassel Hole (Boise ground data).	63
29	Transects at Poverty (Boise ground data)	64
30	Computer produced time trend map of Krassel Hole reach showing sand composition from 1965 to 1979, based on airphoto data	77
31	Computer produced time trend map of Krassel Hole reach showing gravel composition from 1965 to 1979, based on airphoto data	79
32	Computer produced time trend map of Krassel Hole reach showing rubble composition from 1965 to 1979, based on airphoto data	80
33	Computer produced time trend map of Krassel Hole reach showing boulder composition from 1965 to 1979, based on airphoto data	82

Figure No.	Title	Page
34	Computer produced time trend map of Krassel Hole reach showing sand composition from 1972 to 1979, based on ground data	83
35	Computer produced time trend map of Krassel Hole reach showing gravel composition from 1972 to 1979, based on ground data	85
36	Computer produced time trend map of Krassel Hole reach showing rubble composition from 1972 to 1979, based on ground data	87
37	Computer produced time trend map of Krassel Hole reach showing boulder composition from 1972 to 1979, based on ground data	88
38	Computer produced time trend map of Poverty reach showing sand composition from 1965 to 1979, based on airphoto data.	89
39	Computer produced time trend map of Poverty reach showing gravel composition from 1965 to 1979, based on airphoto data	91
40	Computer produced time trend map of Poverty reach showing rubble composition from 1965 to 1979, based on airphoto data	92
41	Computer produced time trend map of Poverty reach showing boulder composition from 1965 to 1979, based on airphoto data	94
42	Computer produced time trend map of Poverty reach showing sand composition from 1972 to 1979, based on ground data	95
43	Computer produced time trend map of Poverty reach showing gravel composition from 1972 to 1979, based on ground data	97
44	Computer produced time trend map of Poverty reach showing rubble composition from 1972 to 1979, based on ground data	98
45	Computer produced time trend map of Poverty reach showing boulder composition from 1972 to 1979, based on ground data	100

Appendix

Figure No.	Title	Page
1	Planimetric map of 1946 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.	127
2	Planimetric map of 1947 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.	128
3	Planimetric map of 1952 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.	129
4	Planimetric map of 1965 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.	130
5	Planimetric map of 1972 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.	131

ACKNOWLEDGEMENTS

Research reported here was funded by the U.S. Forest Service through the Intermountain Forest and Range Experiment Station, Boise, Idaho. This study is a contribution of the Remote Sensing Faculty of the College of Forestry, Wildlife and Range Sciences, University of Idaho.

We are obliged to all who have assisted us in many ways. Particular thanks are due for cooperation and coordination of this work to the following:

(a) Dr. Walter Megahan, Program Manager, Intermountain Forest and Range Experiment Station, Boise, Idaho, for his enlightened direction for this project and his assistance in obtaining necessary data.

(b) Mr. Bert Kulesza, Watershed Specialist, Supervisor's Office, Payette National Forest, McCall, Idaho, for his assistance in obtaining aerial photos and ground data.

(c) Mr. Robert Heller, Research Professor, Remote Sensing, College of Forestry, Wildlife and Range Sciences, University of Idaho, Moscow, Idaho, for his advice on direction of project and reviewing the project.

ABSTRACT

This study, undertaken in October 1979, investigated the feasibility of interpreting bottom sediments in the Krassel Hole, Poverty and Oxbow reaches of the South Fork of the Salmon River and developing an aerial photo interpretation key to evaluate changes in the particle size distribution of the surface of the stream bed material by remote sensing techniques. The interpreted sediments from 1965, 1972, 1976, and 1979 large scale airphotos have been compared with the McCall ground data for the years 1972, 1976, and 1979 and agree within ten percent.

An attempt has been made to use the same visual interpretation technique on small scale photos for years 1946, 1947, 1952, 1965, and 1972. The agreement between the results of large scale air photos and the small scale photos both for the common period 1972 and 1965 is within a 10.5 percent standard error, and detection of sediments is feasible on the small scale airphotos in broad categories of combined sand and gravel and combined rubble and boulders.

Twelve interpreted planimetric maps were used for computing individual sediment area occupied in the channel at a particular period of time. This data were used in linear regression and analysis of variance procedures to study the relationship between time periods and bottom sediment types. The same data were used in computer drawn time trend curves for sand, gravel, cobble, rubble and boulder over the time period from 1965 to 1979.

Thirty-two computer-aided maps were produced for sand, gravel, rubble, and boulder for different periods for two (Krassel Hole and Poverty) of the three reaches. Four such individual maps were mosaiced and photographically reduced, thereby depicting the distribution of an

individual sediment from 1965 to 1979. The minute changes and numerous variations in the sediment distribution over time that were not found significant in the statistical analysis were clearly discernible on these maps. Similar computer-aided maps were produced using ground data sets and results were compared with airphoto data maps. The results in general were in good agreement.

The riverbed elevations of year 1979 were photogrammetrically observed along eight cross-sections on the large scale airphotos and this elevation data were used in the computer drawn profile curves for the eight cross-sections on the three reaches. The profile curves were also drawn using ground data and superimposed on the airphoto data set curves. The average error between the airphoto data and ground data was 1.7 feet with a standard deviation of 1.2 feet.

The study design was modified when BOISE ground data was acquired. In this case cobble sediment was dropped, leaving sand, gravel, rubble, and boulder. This data had been collected along ten transects marked on each of the two reaches used for this part of the study. The computer-aided designed maps were based on this modified design.

The conclusions of this study were based on the interpretation of the planimetric maps, computer plotted time trend curves, compuer-aided designed maps, statistical analysis of the sediments and finally the riverbed elevations in the form of computer plotted cross-section profiles of the three reaches. It was found feasible to interpret sediments, detect time trends and assess changes in the South Fork of the Salmon River using remote sensing techniques. Average error ranged between 10 and 23 percent depending on the type of data compared.

1.0 Introduction

1.1 Background

Stream sediment has been recognized as one of man's major land use problems since the days of the ancient Egyptians, Chinese, and Mesopotamians (Striffler 1964). The relationships between land use or abuse and the amount of sediment in the stream have been observed over the centuries. More than a hundred years ago, the effect of the removal of forest cover in particular was mentioned by Sir Charles Lyell (1849). On a trip to the United States he commented on the effect of forest clearing on the sediment loads. Ashe (1907) discussed the effect of forest clearing and soil type on sediment loads in the Potomac River and suggested that certain highly erodible soils within the watershed should not be cleared when slopes exceed a certain level.

During the United States conservation movement of the 1930's, runoff and erosion received considerable attention. A large share of the work concentrated on comparative erosion rates under various vegetation densities and types (U.S. Dept. Agr. 1940). Relatively high erosion rates occur under open row crops such as corn and cotton while less erosion occurs from small grains, pasture, and hay land. Forest lands are generally recognized as having minimum soil losses. Only recently, modern statistical techniques have made possible reasonably accurate quantitative evaluations of watershed characteristics and conditions upon stream sediment yields.

According to Arnold and Lundeen (1968), increased sediment deposition in the South Fork of the Salmon River from 1950 to 1966 was caused primarily by accelerated logging and road construction on lands with a high erosion hazard. Before 1950, most logging and road construction in

the Idaho batholith was confined to limited areas with gentle slopes where soil erosion hazards were relatively low. To proceed with logging, however, it became necessary to harvest timber on lands with higher erosion hazards similar to those in the South Fork Salmon River watershed. By 1965, 15 percent of the area of the watershed area had been logged. In addition, several hundred kilometers of roads had been constructed. Seventy-eight percent of the logging and 69 percent of road construction were on steep, stream cut lands, the least stable lands in the drainage.

According to Megahan (1972), the situation was further aggravated by severe storms in 1962, 1964, and 1965 that greatly accelerated soil erosion rates from the newly disturbed lands. Arnold and Lundeen (1968) estimated that by 1967 accelerated soil erosion in the watershed had increased sediment loads in the river by 350 percent compared to conditions before 1950.

Platts (1970) concluded that the coarse texture (mostly coarse sand) of soil eroded from the watershed resulted in bed load sedimentation that dramatically altered the size composition of the riverbed. Sedimentation caused severe damage to Chinook salmon spawning areas, burying Chinook salmon and steelhead trout redds under thick blankets of sand.

The concern over degraded river conditions led the U.S. Forest Service to develop an integrated watershed restoration program to remedy the situation. One important action was to declare a moratorium in 1966 on all new logging and road construction in the study area. In addition, a number of watershed rehabilitation practices were instituted to reduce surface erosion on previously disturbed areas and to help reduce mass erosion in high hazard locations; these are reviewed and analyzed by Michelson et al. (1973). Several logging roads were closed and treated

with a variety of stabilization practices including cross ditching, revegetation (both seeding and transplanting), removal of culverts and bridges and removal of road fills. Additional stabilization practices, such as improved drainage, and installation of retaining structures were used on the main access roads.

Megahan, Platts, and Kulesza (1980) conclude that prior to the restoration program, sediment supplied to the river exceeded sediment transport out of the system causing aggradation of a thick blanket of sand on the streambed. The objective of the watershed restoration program was to reduce sediment supply to the river so that stream energy available for sediment transport would exceed sediment supply, thereby allowing the river to transport the excess sediments out of the system. River responses were monitored by cross-section surveys to document changes in bottom elevation, a series of transects to evaluate particle-size distribution on the riverbed in salmon spawning and rearing areas and core samples of the channel bottom to determine changes in the vertical size distribution of the channel substrate in spawning areas. The field work was done during late summer when river flows where low, assuring shallow water for wading, clear water for direct measurement, and maximum stability of sediments.

In conjunction with other studies of stream bed conditions, vertical aerial photographs at a scale of 1:3600 were taken to provide stereoscopic coverage of the entire length of river within the study area. Photo flights were made in 1965, 1972, 1976, and 1979 (Megahan et al. 1980).

In planning for any future timber harvesting, an inventory of the riverbed conditions in South Fork of the Salmon River is a necessity. Such an inventory ideally provides an input to Forest Management to base

their policy decision. To date, attempts at making such inventories have been confined to the most accessible sites on the stream. There are many obstacles to the acquisition of ground data, particularly on a mountainous stream. The field season for collecting ground truth is often short, travel on the ground is blocked by snow and ice during much of the year and is strenuous at any time. Great fluctuations in water volume leave only a short period in late summer when comparative measurements can be made. Thus, ground acquisition of data about bottom sediments and making direct spirit levelled measurements is generally too time consuming and costly to be practical. Other possibilities such as aerial reconnaissance using planes or helicopters are unproductive, expensive, and hazardous in rugged mountains (Roscue et al. 1967).

A step toward solution of the problem is the use of remote sensing techniques and photogrammetric measurements for reasonably accurate inventory. Remote sensing is considered to encompass all means of gaining information without direct contact over distances from a few feet to a few miles or even hundreds of miles. Primary emphasis to date has been placed on applications from distances associated with space, high altitude, or lower altitude airplane operations, but some photogrammetric applications of great potential value can also be carried out on the ground. Remote sensing can provide unbiased and accurate information in real time, in volumes not otherwise attainable before and in a very useful format. Yet ability to utilize even the available information to the fullest extent has not been developed (Belchar 1967).

Remote sensing systems which have emerged can be categorized as (a) photographic, (b) scanners, and (c) radar. In this case, aerial photographs are already available and we must use the existing wealth of photographic

documentation. Besides aerial photography represents the most advanced stage of development of all sensors and color photography takes first place among photographic variations. Scanning systems and radar lack both development and interpretation support and are expensive. Little needs to be quoted in the air photographic field. Ground resolution, stereo coverage, scale, and reliability of equipment and film are well known and time tested. Assuming that suitable airphotography can be obtained, all the primary applications of remote sensing can be achieved with aerial remote sensing using conventional photographs (Belchar 1967).

Many forestry applications of remote sensing are already operational. Aerial photographs are conventionally used as the basis for inventory, cruises, cover maps, acreage studies, fire control, and airphoto volume tables (Manual of Photogrammetry 1966). In regard to sedimentation, airphotographic techniques have been employed in the study of coastal processes (Shephard 1950, Sonu 1964, Dolan et al. 1973) and shoreline erosion and accretion have been measured (Wanless et al. 1968, Lansfelder 1973, Tanner 1978). Sequential aerial photography has been used to quantify changes in shoreline orientation and overwash distribution (Zeigler and Ronne 1957, Boc and Lansfelder 1977, Hosie and Cleary 1977). Quantification of changes in coastal topography using simple parallax measurements by Harold (1980) revealed major changes in dune topography over a relatively short time span in Currituck Spit, Virginia-North Carolina. Remote sensing techniques for rapid, cost effective assessment of erosion in New Zealand have been discussed by Stephens (1976), Trustrum and Stephens (1978) and by Page (1980). In soil conservation research, Stephens (1981) assessed the soil erosion

and catchment conditions by using a combination of conventional wide angle aerial photography and 70-mm format multispectral photography. The aerial photography was used to detect soil conservation in New Zealand, a geologically unstable country, where transitory changes of erosion and vegetation are more frequent than in most other countries.

Greentree and Aldrich (1976) used conventional photo interpretation techniques to determine streambed conditions by examining large scale color photographs under two to four power magnification. Bottom types were classified by size of particle and physical appearance. They categorized bottom types into one of four size classes: gravel--1 to 3 inches, rubble--3 to 6 inches, boulder--6 to 12 inches, and rocks--12 inches or more. The best overall scale and film for evaluating streambed conditions was normal color at 1:1584. Rubble, rocks and gravel were correctly identified in most instances at the 1:1584 scale.

In a comprehensive review paper, Cordone and Kelly (1961) summarized the evidence indicating that fine sediment is detrimental to aquatic life in streams. Many other researchers (Bjornn 1969, Phillips 1975, Coble 1976) have determined the amounts of fine sediments which reduce the survival of salmonid embryos in the gravel or prevent them from emerging successfully as fry. In addition to its detrimental effects on fish embryos, sediment could reduce the capacity of rearing areas by covering or filling the stream bottom with sand, decreasing the amount of fish habitat and the abundance of aquatic insects, thereby decreasing the growth and/or density of fish in the stream (Bjornn 1977). The fine sediment found in most streams of the Idaho batholith was primarily a coarse sand. Megahan (1975) found 64 percent sand composition (size .05 mm to 2.0 mm) and 31 percent gravel (size 2.0 mm

to 7.9 mm). Bjornn and others (1977) designated all particles less than 6.35 mm in diameter as fine sediment.

Several authors have investigated the sediment composition preferred by the salmonids. Hunter (1973), Reiser, and Wesche (1977) found that gravel ranging from 0.6 to 10.2 cm was preferred for spawning. Reiser and Bjornn 1979, recommend that for incubation of salmonid embryos, fine sediments less than 6.4 mm in size should form less than 25 percent of the overall composition. Spruce (1947) reported that rubble seems to be the most productive substrate for the juvenile rearing of salmonids. Reiser and Bjornn (1979) recommend coarse gravel, 3.2 to 7.6 cm and rubble, 7.6 to 30.4 cm as the optimum composition for fish food production. These authors further state that suspended and deposited fine sediment can adversely affect salmonid rearing habitat if present in excess amounts.

This study illustrates how riverbed sediments can be detected, interpreted and measured using existing conventional aerial photography and simple parallax measurements. Furthermore, small scale black and white sequential stereophotography dating from 1946 and large scale normal color photography taken since 1965 have been combined. This study illustrates the potential for a unique contribution of remote sensing techniques which generates comprehensive, reliable information for detecting time trends in riverbed sediments in the South Fork of the Salmon River.

1.2 Objectives

Generally the study will evaluate changes in the particle size composition of the surface of stream bed materials and changes in channel cross-section shape using available aerial photography. Specifically, we will:

(a) devise a remote sensing scheme for detecting river bottom sediments;

(b) planimetrically map the channel properties of water and bottom sediment size classes on aerial photography of various ages and scales;

(c) plot channel cross-section from large scale aerial photos taken in 1965, 1972, 1976 and 1979;

(d) statistically analyze the aerial photo data to detect time trends;

(e) enhance the final products through computer mapping.

1.3 Experimental Design

The experimental design of the study based on the foregoing objectives was set up as in Figure 1. The test of null hypothesis states that the mean composition of sand, gravel, cobble, rubble, and boulder present in the river channel did not change over time against the alternative hypothesis that the mean composition of sediments in the riverbed has changed. The null hypothesis is indicated by H_o. In case the null hypothesis is rejected, an alternative hypothesis, indicated by the symbol H_a, is accepted.

The information forming the basis for a decision has been obtained from the aerial photo interpretation as outlined in the procedures. The data comprise both elevations of the cross-sections of the riverbed and the percent distribution of sediments. The test statistic was computed using these data and compared with F-values obtained from statistical tables. The statistical test was considered as one of the four approaches. The second method consisted of a comparison of the planimetric maps of sediment distribution prepared from the different years of aerial photography. The third approach was based on the comparison of riverbed channel profiles, contour maps, and finally the computer produced maps.

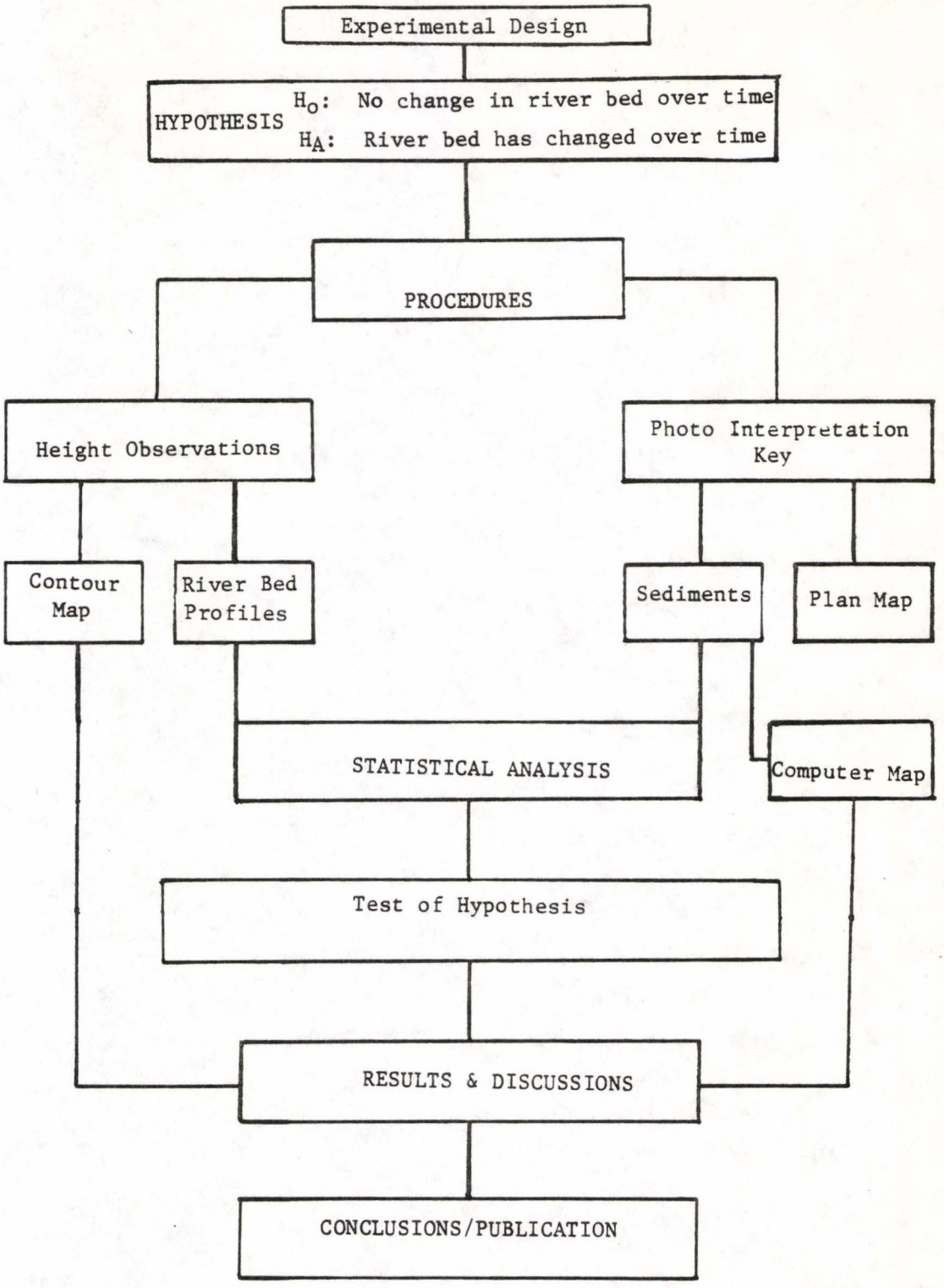


Figure 1. Experimental design of the study.

2.0 Methods and Procedures

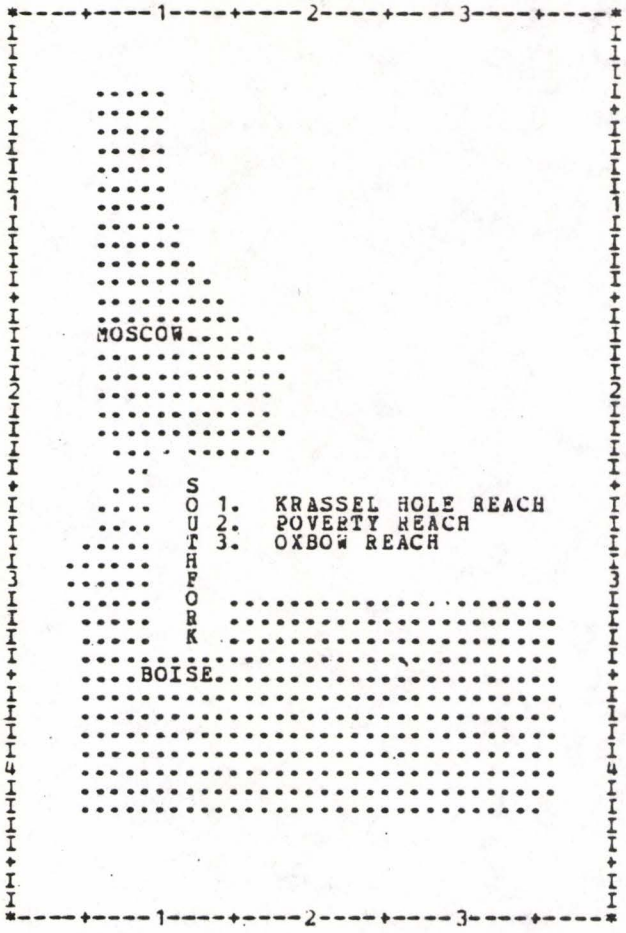
2.1 Study Area

The South Fork of the Salmon River (Plate 1) is a major tributary of the Salmon River and is located in the Idaho batholith, a 16,000 square mile (41,400 square km) area of granite rocks in Idaho and Montana (Megahan et al. 1980). The batholith is almost entirely mountainous and forested. Typically shallow, coarse-textured soils are found on steep slopes. Soils of this type are extremely erodible. Localized, high intensity rainstorms of short duration are common during the summer. At other times of the year, more general storms occur, often in conjunction with melting snow packs. Following soil disturbance, the combination of steep topography, high soil erodibility and transport energy from rain storms and snow melt often results in dramatically accelerated erosion.

Three reaches of the South Fork were studied. Krassel Hole and Poverty spawning areas extend over a 3000-foot reach and the Oxbow reach was spread over a 6000-foot length. The three reaches were interpreted from bank to bank and analyzed on the aerial photographs.

For two specific cross-sections in Krassel Hole, three in Poverty spawning area and three in the Oxbow reach, ground data were collected by personnel of the Payette National Forest, McCall, Idaho, and will be referred to as "McCall data" in future references.

Ground data were also separately collected by personnel of the Intermountain Forest and range Experiment Station, Boise, Idaho, for ten transects at both Krassel Hole and Poverty reach. These did not coincide with the locations of the eight McCall cross-sections. In view of this additional source of ground data, the aerial photographs were separately reinterpreted in the vicinity of these ten transects. This ground data will be addressed as "Boise data" in subsequent references.



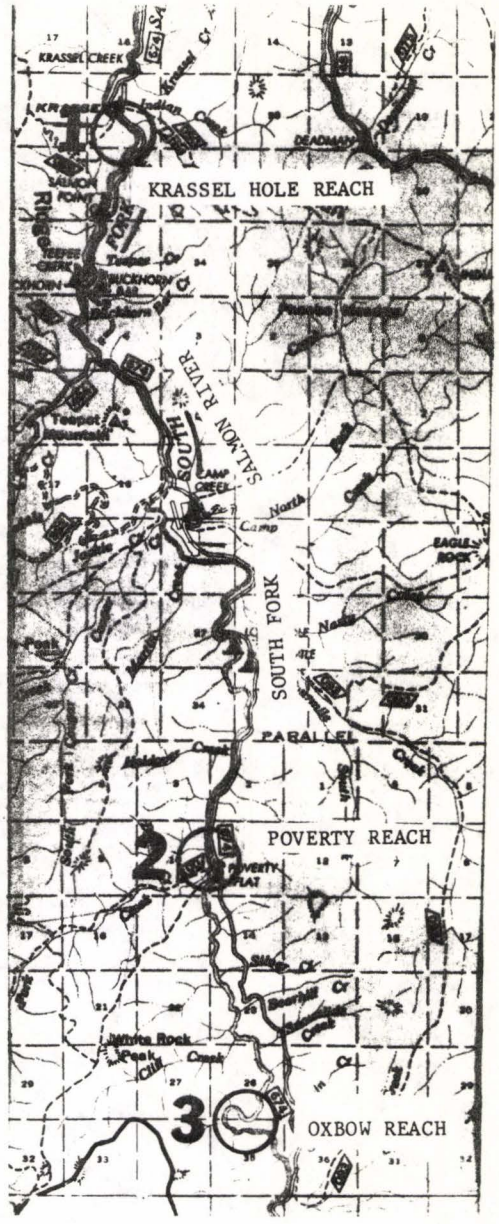


Plate 1. Geographic location of the area of study showing three sites: 1) Krassel Hole Reach, 2) Poverty Reach, and 3) Oxbow Reach on the South Fork of the Salmon River in the State of Idaho.

2.2 Acquisition of Ground Data

The McCall data were acquired on the following dates:

(1)	Krassel Hole #2 - October 30, 1979	Krassel Hole area
(2)	Krassel Hole #3 - October 30, 1979	
(3)	Oxbow Camp Creek - October 31, 1979	
(4)	Lower Oxbow (above breech) - October 31, 1979	Oxbow area
(5)	Upper Oxbow - October 31, 1979	
(6)	Lower Poverty - November 1, 1979	
(7)	Poverty - November 2, 1979	Poverty spawning area
(8)	Upper Poverty - November 2, 1979	

The ground data consisted of spirit levelled heights, sediment composition, and gradient of the streambed, upstream, downstream and on the line. The sediment sizes were estimated using an underwater glass viewer which revealed an area 1x3 feet square. Estimates of the percentage of each class of sediment were taken along each cross-section at every break in slope or every 4 to 5 feet, whichever came first.

On August 19, 1980, final planimetric maps of Krassel Hole, Oxbow and the Poverty Spawning reaches were taken to the sites on the river, where Mr. Bert Kulesza, Payette National Forest watershed specialist, and the two authors checked the reliability of the interpretations. The photo interpreted data agreed with the ground conditions at all sites, except at the Upper Poverty site where the "sand" type was found to be completely missing on the ground.

2.3 Aerial Photography

Information obtained from aerial photographs is very much dependent on resolution and scale. In this study there was no control over these factors because the photographs were flown in the past, many for other purposes.

Aerial photography used for the study area is listed in the following table.

The large scale (1:4000) was used for detailed interpretation of sediments as well as for parallax measurements for heights. All sites had stereoscopic coverage. Enlargement of small scale photographs was considered, but was dropped for want of availability of the color negatives.

Table 1. Existing aerial photography of the study area.

Year of aerial photography	Scale and film type	Calibrated focal length
1946	1:25,000 B&W	209.47(mm)
1947	1:25,000 B&W	209.47(mm)
1952	1:50,000 B&W	151.10(mm)
1965	1:4000 color and 1:40,000 B&W	152.95(mm)
1972	1:4000 color and 1:24,000 B&W	153.23(mm) and 152.47(mm)
1976	1:4000 color	209.94(mm)
1979	1:4000 color	209.94(mm)

2.4 Determination of Tilt

One model for each reach was selected for determination of tilt. This was done only for the large scale photographs. The mean tilt determined graphically was as follows:

Table 2. Estimates of tilt in the photographs.

Year of Aerial Photos	Magnitude of Tilt
1979	2°56'
1976	3°39'
1972	5°22'
1965	4°05'

In view of tilt exceeding 3°, only the 1979 aerial photography was found suitable for contouring. Parallax observations for contouring were made only for the Krassel Hole reach using 1979 air photos. Height

measurements within the relatively small area of a cross-section were considered accurate for depth measurements.

Tilt displacement did not significantly affect planimetric accuracy and was ignored for interpretation purposes.

2.5 Interpretation of Bottom Sediments

The aerial photographs of all available years were scrutinized and prepared for work. The work commenced from the latest photography. The classification of particle size for the initial part of this study using the McCall data was fixed as follows:

(a) Sand - less than 0.25 inch.
(b) Gravel - greater than 0.25 but smaller than 4.0 inches.
(c) Cobble - greater than 4.0 but smaller than 12.0 inches.
(d) Rubble - greater than 12.0 but smaller than 36.0 inches.
(e) Boulders - greater than 36.0 inches.

The riverbed to bank full stage was stratified into polygons containing dominant and co-dominant sediments based on photographic characteristics of shape, size, pattern, tone and texture. Tone and variation in textures helped in stratification of the broad categories. Individual sediments had their own peculiarities, like smooth or coarse surface and scattered pieces. Having outlined a pocket of identical tone and texture, the size of the particles was determined by using a microcomparator reticle under 4X-10X magnification using a Bausch & Lomb stereoscope over a Richards light table. The reticle of the microcomparator was placed directly on the air photo and the measurement noted. This factor confirmed the type of the sediment. Percentage of each category was estimated if more than one type was present in the polygon.

2.5.1 Dichotomous interpretation key and interpretation procedure

A dichotomous interpretation key was developed for interpretation and is shown in Figure 2. Each sediment has the symbol listed below and

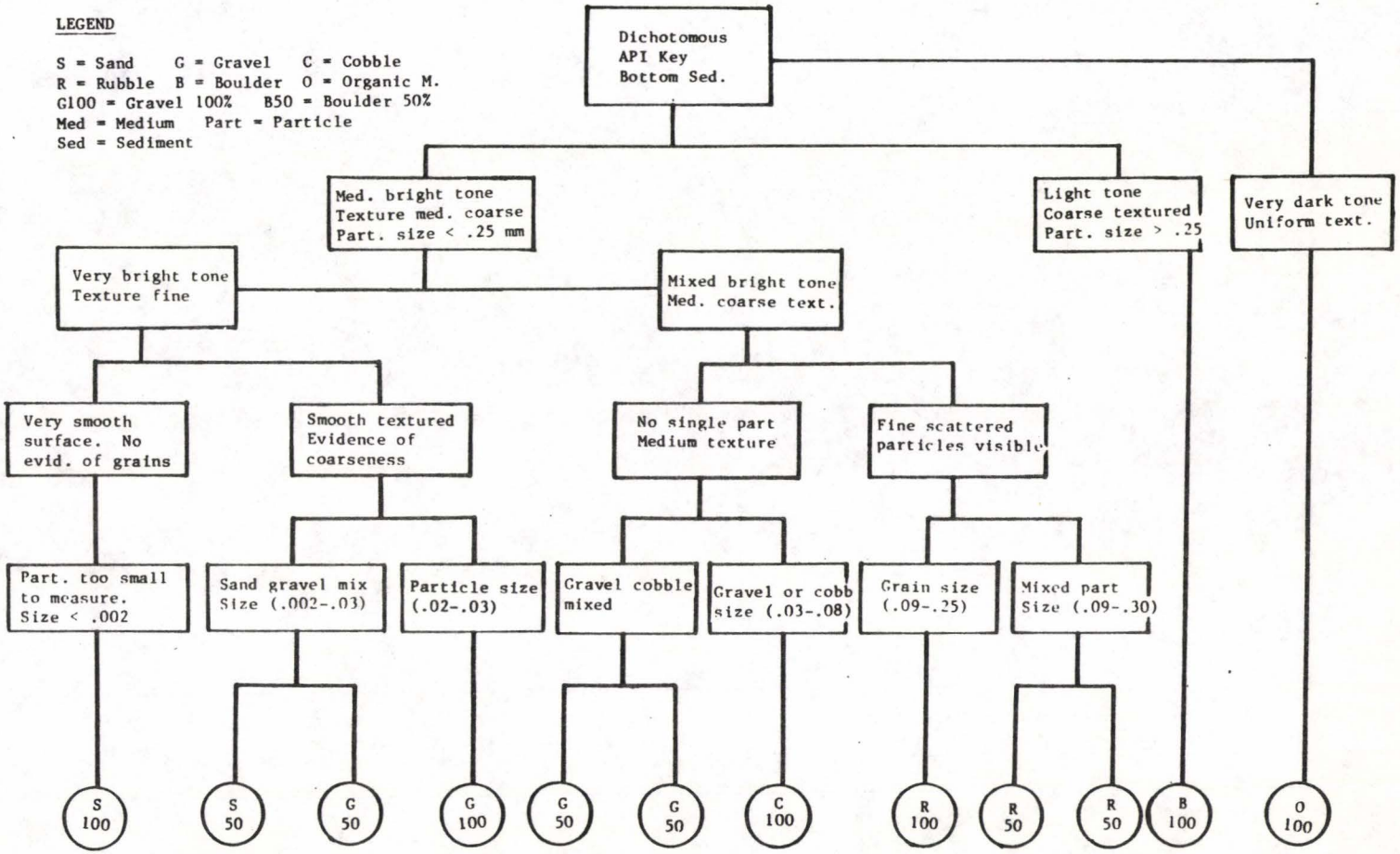

LEGEND
S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder O = Organic M.
G100 = Gravel 100% B50 = Boulder 50%
Med = Medium Part = Particle
Sed = Sediment
Dichotomous API Key Bottom Sed.
Med. bright tone Texture med. coarse Part. size < .25 mm
Light tone Coarse textured Part. size > .25
Very dark tone Uniform text.
Very bright tone Texture fine
Mixed bright tone Med. coarse text.
Very smooth surface. No evid. of grains
Smooth textured Evidence of coarseness
No single part Medium texture
Fine scattered particles visible
Part. too small to measure. Size < .002
Sand gravel mix Size (.002-.03)
Particle size (.02-.03)
Gravel cobble mixed
Gravel or cobb size (.03-.08)
Grain size (.09-.25)
Mixed part Size (.09-.30)
S 100
S 50
G 50
G 100
G 50
G 50
C 100
R 100
R 50
R 50
B 100
O 100

Figure 2. Dochotomous interpretation key for riverbed sediments in a mountain stream.

the photo size is based on a 1:4000 scale photo. If there is more than one sediment in a polygon, percentage of each type is shown in tens, except where two types are indicated at 50 percent each, in which case no percent is shown.

Sediment	Symbol	Size on photo of 1:4000
Sand	S	< .002 mm
Gravel	G	0.002-0.02 mm
Cobble	C	0.02-0.10 mm
Rubble	R	0.10-0.22 mm
Boulder	B	> 0.22 mm

Examples

SG = 50% sand, 50% gravel
S7G3 = 70% sand, 30% gravel
S = 100% sand
C2R8 = 20% cobble, 80% rubble

The sequence of steps used in interpretation was as follows:

Step 1: Look for the identical tone/texture combination and outline the area of close similarity. This should be done under stereoscopic fusion. The tone may be either bright or dark. The texture may be fine or coarse.

Step 2. Using the microcomparator, determine the size of sediments at several places within the polygon. The size should be reduced to the negative scale for this purpose.

Step 3. Determine whether more than one category is present in the polygon. This will be evident from the measurements taken under step 2. Usually more than one category/type of sediment will be found, though one will be the dominant type.

Step 4. Having determined the number of types in the polygon, estimate the percentage of composition of each type of sediment. Any logical approach may be followed for this. The total for any given polygon must equal 100 percent. Pope's "cramming method" was found to be satisfactory for this purpose (Pope 1960).

Step 5. Make all estimates to the nearest 10 percent. Estimates less than ten were not found to be consistent.

Step 6. Proceed to identify the next type in the next enclosed polygon. In this manner cover the entire strip systematically.

Tone, texture and surface roughness were the main guiding factors in classification. The comparator confirmed the size. At times, tonal colors on a given photograph may show the sand and boulders as the same color but of different degrees of surface smoothness. Therefore, use of the comparator was made frequently.

2.5.2 Particle size on negative scale (1:4000)

It is worthwhile to mention that in spite of the irregularity in morphology, there is a fairly regular trend of any dominant sediment size with coarsest material in the wet channel zones and finer material on either side. Where gravel was extensive on the bed surface, this showed up very bright on the air photos and led to higher estimates for the sand and lower for gravel in that polygon. Dark tones due to organic material over a sand surface were mistaken for coarser sediments. Distinct dark tones appear on the air photos not only due to organic matter in the channel but also due to the mineral composition of the sediments.

2.5.3 Interpretation of sediments on small scale airphotos

The airphoto stereoscopic record of the South Fork of the Salmon River dates back to 1946. The air photography is black and white and varies in scale from 1:25,000 to 1:50,000. The airphotos were prepared for interpretation and were examined both on the Richards Light Table, model MZM, fitted with a Bausch & Lomb stereoscope, and the Zoom Transfer Scope (model ZT4-H). The latter was found very convenient and efficient for interpretation of small scale airphotos. After interpretation, a

planimetric map at a scale of 1:2000 was drawn on clear mylar sheets. This was finally scaled to 1:4000 for comparison with the large scale airphoto planimetric maps.

Because of the poorer resolution on the small scale imagery, the size class categories were consolidated into broader classes for interpretation. The characteristics of pattern, tone, and texture were used as the size of particles could not be distinguished. Due to these notable difficulties, interpretation of small scale airphotos was done for 1946, 1947, 1952, 1965 and 1972 in the case of Krassel Hole reach only, and Poverty and Oxbow reaches were not taken up.

2.6 Area Determination of Sediments

The area of each of the polygons was measured using a Numonics Graphics Calculator. The total area of each sediment type was calculated and plotted on a Time Trends graph for each year of the years measured.

2.7 Determination of Riverbed Elevations and Contours

It was desired that configuration of the channel bed be depicted by contouring the river bed using parallax bar observations. For this purpose 30 well distributed points were selected over the area. Each point was measured three times and the mean accepted for the point. A Condor stereoscope and a parallax bar were used to obtain parallax measurements in order to determine depth of the cross section.

In order to ascertain the precision of the parallax observations, one point chosen at random was measured on the air photo. The parallax of this point was measured 20 times on different occasions after the stereopair was aligned and fastened down. Table 3 summarizes these

measurements. By this procedure a reliable estimate was obtained of the variance of the population of parallax measurements.

Table 3. Parallax measurements of one point on each stereo pair.

1979	1976	1972
15.48 (mm)	16.25 (mm)	16.83 (mm)
15.46	16.25	16.82
15.45	16.25	16.84
15.44	16.23	16.85
15.44	16.24	16.82
15.44	16.24	16.83
15.44	16.24	16.84
15.45	16.23	16.83
15.44	16.24	16.84
15.44	16.24	16.84
15.44	16.24	16.85
15.45	16.25	16.83
15.44	16.24	16.82
15.44	16.24	16.82
15.44	16.24	16.84
15.44	16.23	16.85
15.43	16.25	16.85
15.43	16.24	16.84
15.43	16.25	16.84
15.44	16.25	16.85
Mean = 15.44 mm	Mean = 16.24 mm	Mean = 16.84 mm
S.D. = .01 mm	S.D. = .01 mm	S.D. = .01 mm

Elevation difference was calculated by using:

$$\Delta h = \frac{\Delta p(H - h)}{b}$$

where

b = photo base (mm)
(H - h) = flying height (feet)
Δp = parallax difference (mm)
Δh = difference in elevation (feet)

However, due to tilt higher than three degrees, only 1979 air photos could be used for contouring. The contour interval was kept at 0.5 feet and scale of the map at 1:4000. The contour map of Krassel Hole channel for year 1979 has been prepared and included.

2.8 Statistical Analysis

Statistical analysis was carried out under three different parts. Part one used air photo data from the three reaches: Krassel Hole, Oxbow and Poverty Reach for 1965, 1972, 1976 and 1979. Year and reach were treated as independent variables; sand, gravel, cobble, rubble and boulder were treated as dependent variables. Multivariate analysis of variance procedure was applied using the Statistical Analysis System (SAS) (SAS Institute 1979). The second part contains analysis of 8 cross-sections of McCall ground data versus airphoto cross section data for the same period of time, namely 1965, 1972, 1976 and 1979. Cross-section and year were treated as independent variables and sediments as dependent variables. The third part of the analysis pertains to Boise data derived for the modified design using ten transects for both Krassel Hole and Poverty reach only.

2.9 Computer-Aided Maps for Depicting Time Trends

Computers allow greater flexibility in the manipulation of data and graphic symbolism. The capability of automatic data handling enabled us to produce individualized time trend thematic maps showing specialized data. SYMAP, the most widely known and distributed mapping program of the Laboratory for Computer Graphics and Spatial Analysis, Graduate School of Design, Harvard University was used to map the time trends in the riverbed sediments.

SYMAP is designed to produce graphic displays of spatially distributed data with as few constraints as possible. This program package produces output on a standard line printer and specialized output devices are not needed. SYMAP includes over 35 options for controlling the characteristics of the output map, all of which have default values. It can produce choropleth, contour or proximal maps. Several maps can be

produced for a single input deck as SYMAP can internally save information for reuse in successive maps. This capability of SYMAP was utilized in producing the time trend maps.

We used airphoto data of 10 transects at Poverty and Krassel Hole reaches to produce contour maps for each of the four sediments, sand, gravel, rubble and boulder. Contour maps are used to describe a continuously varying data function from observations made at discrete locations. SYMAP interpolates from known data point values to construct a continuous surface. Interpolated points on the surface are assigned to an interval. A unique printer character is used to represent each interval and the computed surface is displayed using the appropriate symbol at each point location.

The data used were irregularly spaced. In this case sediment percent was assigned to a point selected in the mid-stream at each of the 10 transects. There were no unknown data values and no limits were imposed on the SYMAP interpolation algorithm for contour mapping. The interpolation algorithm uses a weighted average of known data values based on an inverse distance model with correction for other characteristics of the data surface, such as special configurations of the data points. The resultant computed surface passes through each of the known data points.

Input to SYMAP was given in a series of packages, each of which described one type of feature of the area to be studied. These specify the outline of the map, such as Krassel Hole or Poverty reach, in this case. The outline of river channel at these reaches was digitized manually using the top leftcorner (Northwest corner) as the origin of the coordinates. The graph paper having the smallest square equal to

0.1 inch was considered adequate for this purpose. In all there were 101 discrete points having y and x values. This package was called A-OUTLINE package. In the coordinate system of SYMAP y values are entered first and are followed by x-values. The first point of the polygon is repeated at the end and thus becomes the last point as well.

The second package was called B-DATA POINTS. This specified the location and the value of each data point. The 10 transects were identified as data points and a mid-channel point on each transect was digitized and recorded in y and x values.

The third package was called C-OTOLEGENDS, it specified the location and content of map cosmetics such as legends and titles. Standard format was used to input this information. The second part of this package was named C-LEGENDS and was used for entering maximum and minimum values in the map legends. This package was found easier to use than C-OTOLEGENDS as it works on rows and columns and not on y and x values.

The fourth package, called E-VALUES, was used to assign a sediment value to each of the B-DATA POINTS. Only one value can be assigned at a time to a particular data point. In this case we assigned sand percent as interpreted on the airphotos of 1965 and produced a map showing sand distribution in 1965. This map was followed by 1972, 1976 and 1979 sand distributions. In this manner there were four separate maps showing sand compositions, each representing one year at a time. Similar maps were produced for gravel, rubble and boulder compositions for the years 1965, 1972, 1976 and 1979. In all there were 16 such time trend maps of Krassel Hole reach produced using airphoto data pertaining to four different periods and four different sediments. Finally a set of 4 maps

of a given sediment type were mosaiced and photographically reduced and compiled on one page in a compact form for visual analysis of time trends.

The fifth package was called "F-MAP" which defined the characteristics of each output map; its size, contents, number and range of data intervals. Elective 12 was used to store the values of the computed data surface for input to other multiple maps. Under this option we could produce all the 16 maps in one complete package. Each map has its own different title and class values. In other words, a series of contour maps was produced in a single run. Map 1 included A-OUTLINE, B-DATA points, C-OTOLEGENDS, E-VALUES and F-MAP packages. Elective 8 and 12 were included in the F-MAP package. Elective 12 was useful to carry forward data required to be used in the subsequent maps. Elective number 8 was used to suppress contour lines. For the second map and the subsequent ones, E-VALUES, C-OTOLEGEND and F-MAP packages were considerably different.

The SYMAP manual was followed to run the program. The program itself is written in FORTRAN IV level G and can be run in 150k bytes of core memory. It was run on an IBM 370 computer at the University of Idaho Computer Center.

3.0 Results

The results of the study are summarized under the following paragraphs. The results of the modified design follow those of the initial design.

(a) The scheme of sediment interpretation has been illustrated in the outline of the dichotomous interpretation key, Figure 2.

(b) Twelve planimetric maps of the channel depicting riverbed sediment size classes and percentages of various ages and classes are presented for Krassel Hole, Oxbow and Poverty reaches as Figures 3-14. Area of each type is given in Table 4.

Three plots of time trend curves are presented for the three reaches based on the sediment percentage data of these reaches (Figures 15-17).

Tables 6 and 7 show comparisons between sediments as obtained from aerial photo interpretation and ground method.

(c) Eight plots of riverbed elevations of the cross-sections of the three reaches are shown. These graphs compare photogrammetrically measured heights versus ground measured heights and are shown in Figures 20 to 27.

Table 8 shows comparisions between aerial and ground elevations of the eight cross-sections. A contour map of Krassel Hole is given for the 1979 aerial photographs. This is shown in Figure 19.

(d) Statistical analysis is based on sediment data to detect time trends over a period of time. Results are shown in Tables 15-18.

(e) Thirty-two computer-aided designed maps were produced depicting individual sediment composition for 1965, 1972, 1976, and 1979. To enhance the final presentation of the data, four maps of the same sediment type were photographically reduced, mosaiced and compiled into one

composite map. This step strengthened the visual impact and presented at a glance the distribution pattern prevalent over 15 years. Similar maps were produced for ground data.

3.1 Time Trends

3.1.1 Krassel Hole Reach

The seven years sediment data were used to plot time trend curves (Figure 15) by using the "PLOTALL" computer program. The large scale air photo data pertained to years 1965, 1972, 1976 and 1979. The small scale data were from 1946, 1947, 1952, 1965 and 1972 (Figures 1-5, Appendix).

3.1.2 Oxbow Reach

At Oxbow reach sediment data from 1965, 1972, 1976 and 1979 large scale aerial photos were used. The time trend curves (Figure 16) were plotted using time as the independent variable. The same "PLOTALL" computer program was used for drawing the curves. No small scale data was derived for Oxbow reach.

3.1.3 Poverty Reach

Sediment data from 1965, 1972, 1976 and 1979 large scale air photos were used. The time trend curves (Figure 17) were drawn on "PLOTALL" computer program in a similar manner as above.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

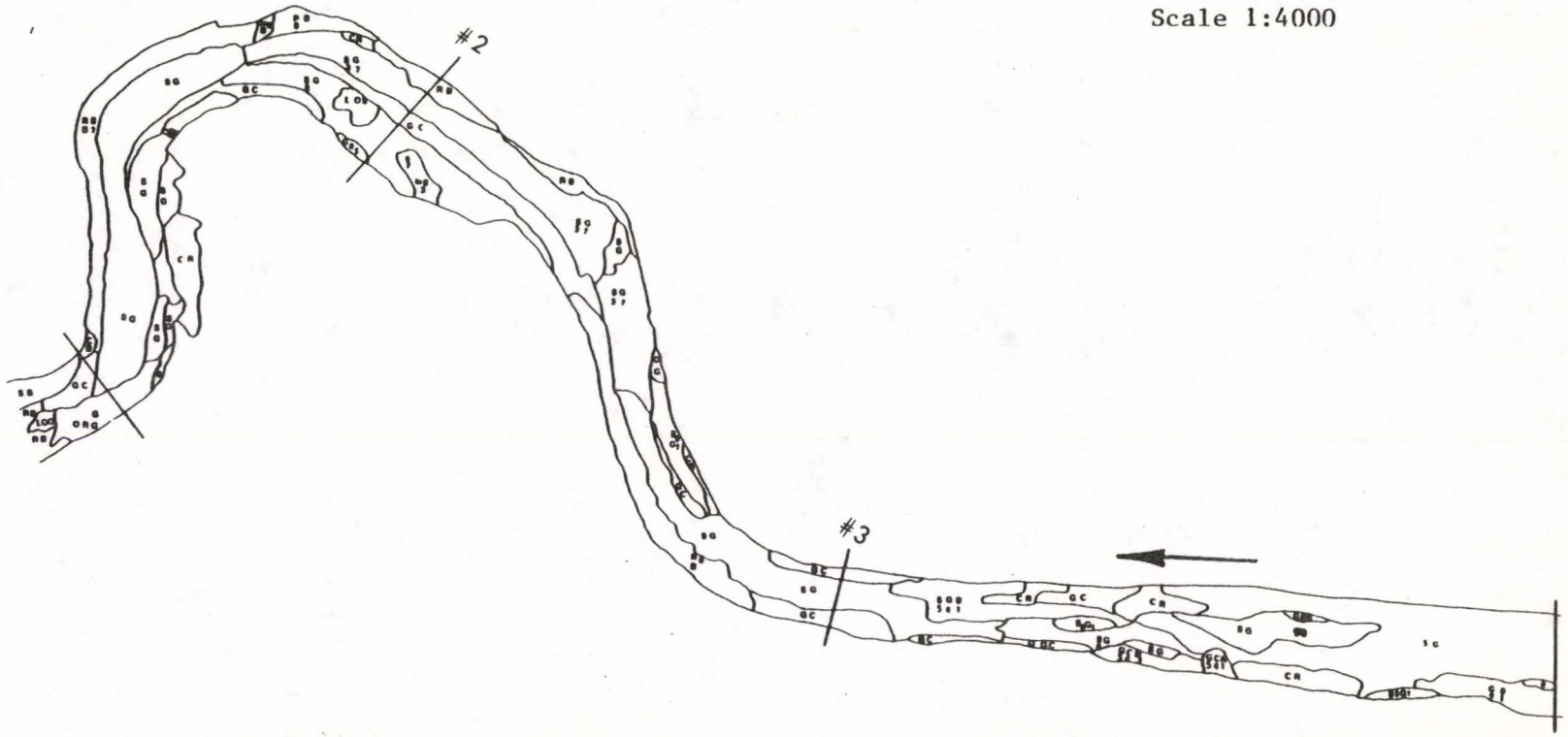


Figure 3. Planimetric map of 1965 riverbed sediments at Krassel Hole reach.

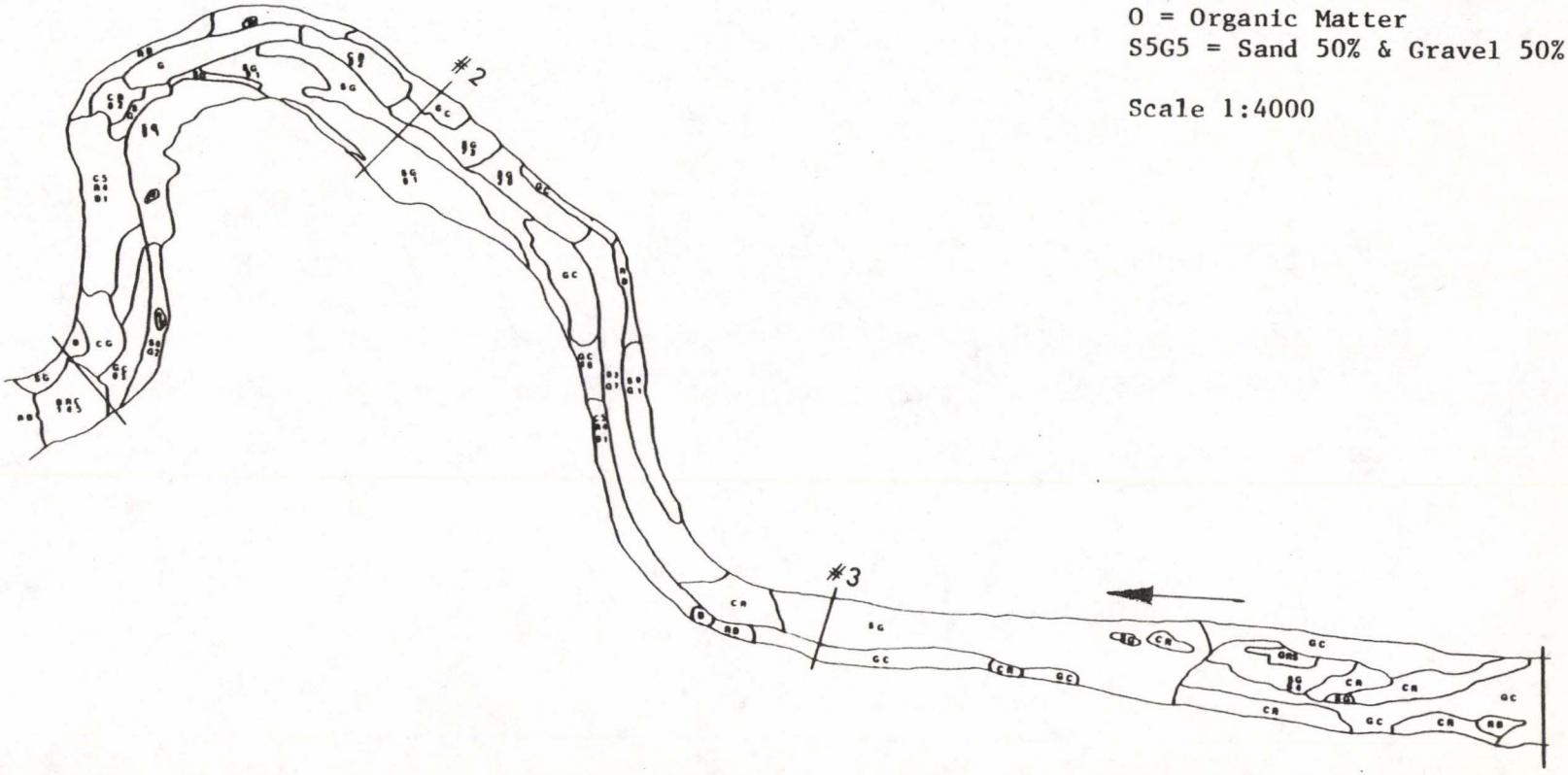


Figure 4. Planimetric map of 1972 riverbed sediments at Krassel Hole reach.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

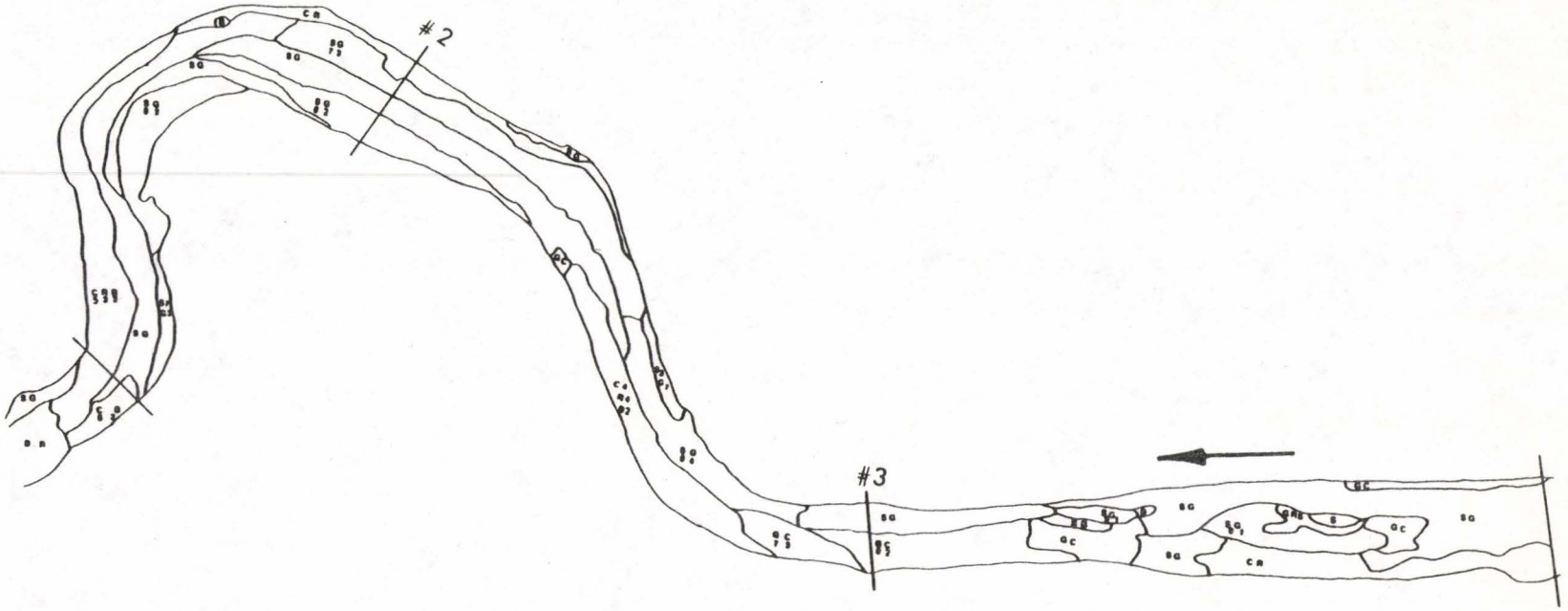


Figure 5. Planimetric map of 1976 riverbed sediments at Krassel Hole reach.

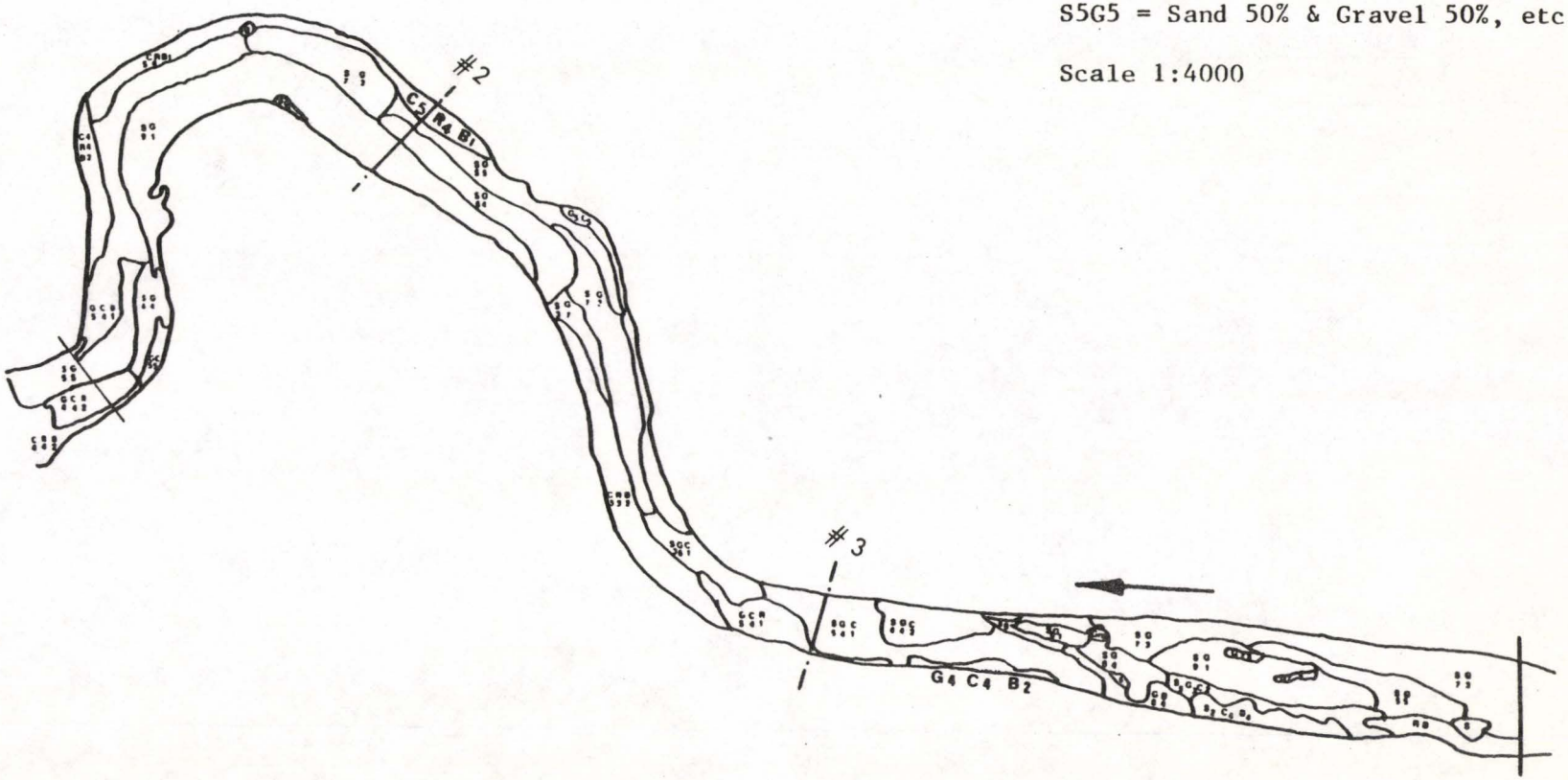


Figure 6. Planimetric map of 1979 riverbed sediments at Krassel Hole reach.

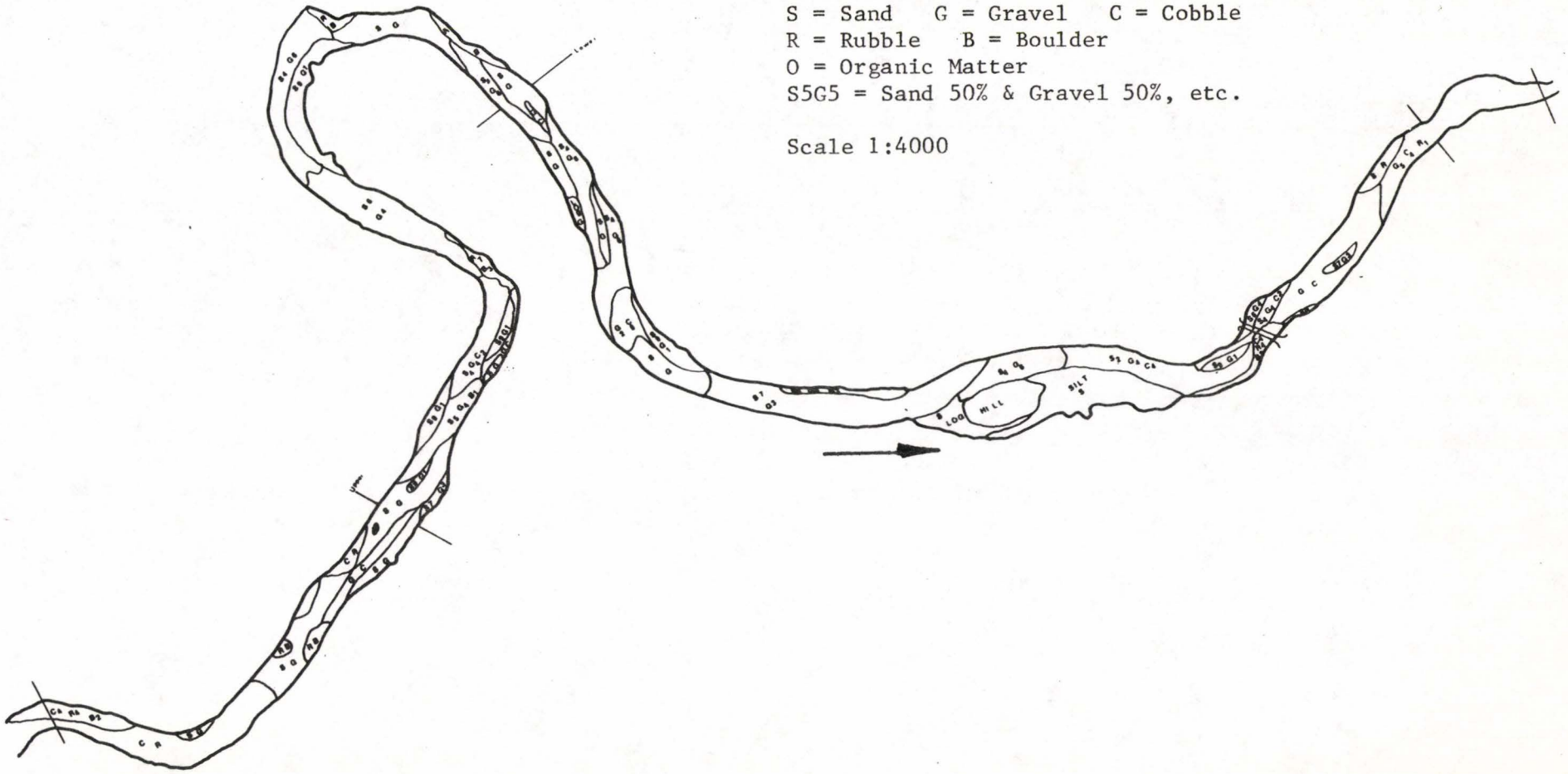


Figure 7. Planimetric map of 1965 riverbed sediments at Oxbow reach.

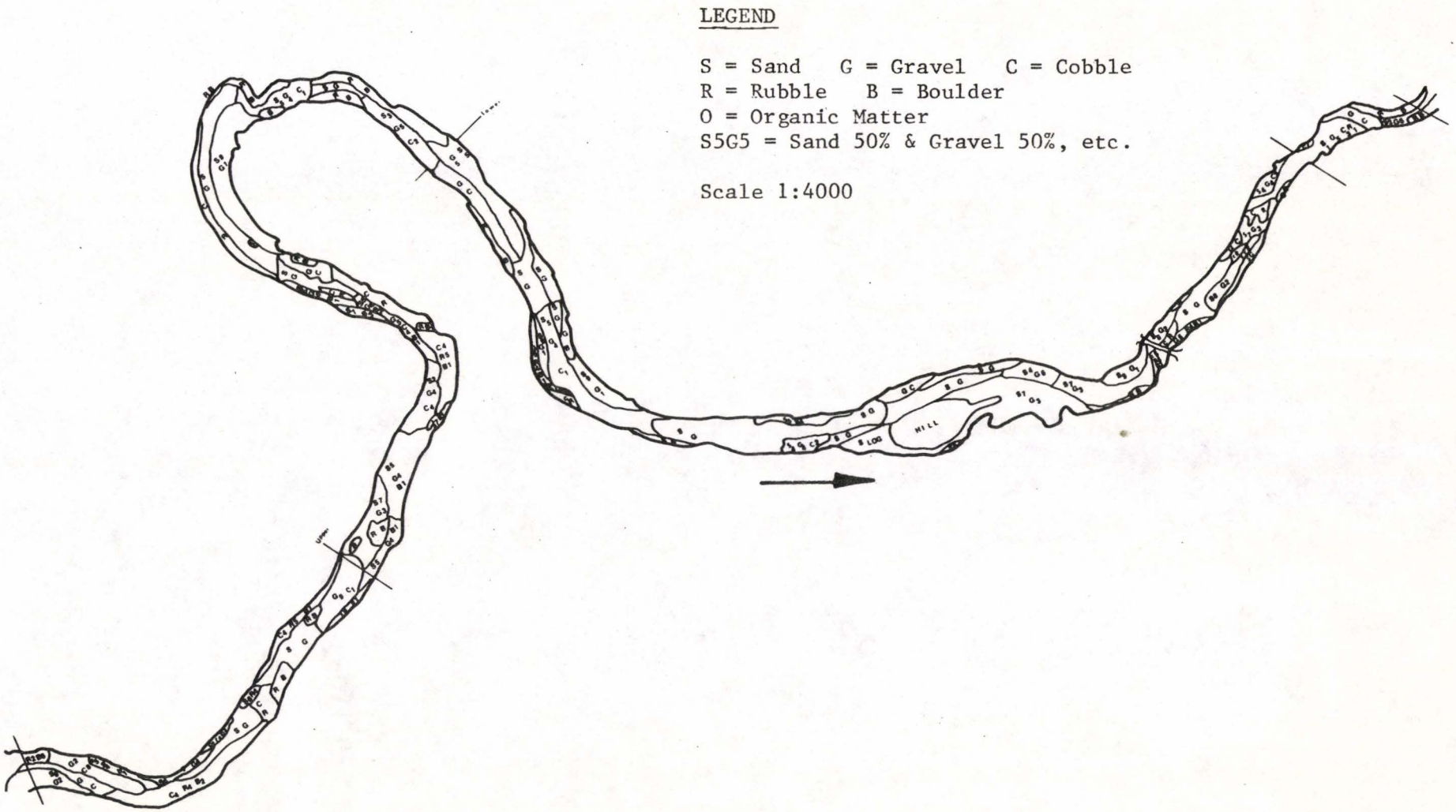


Figure 8. Planimetric map of 1972 riverbed sediments at Oxbow reach.

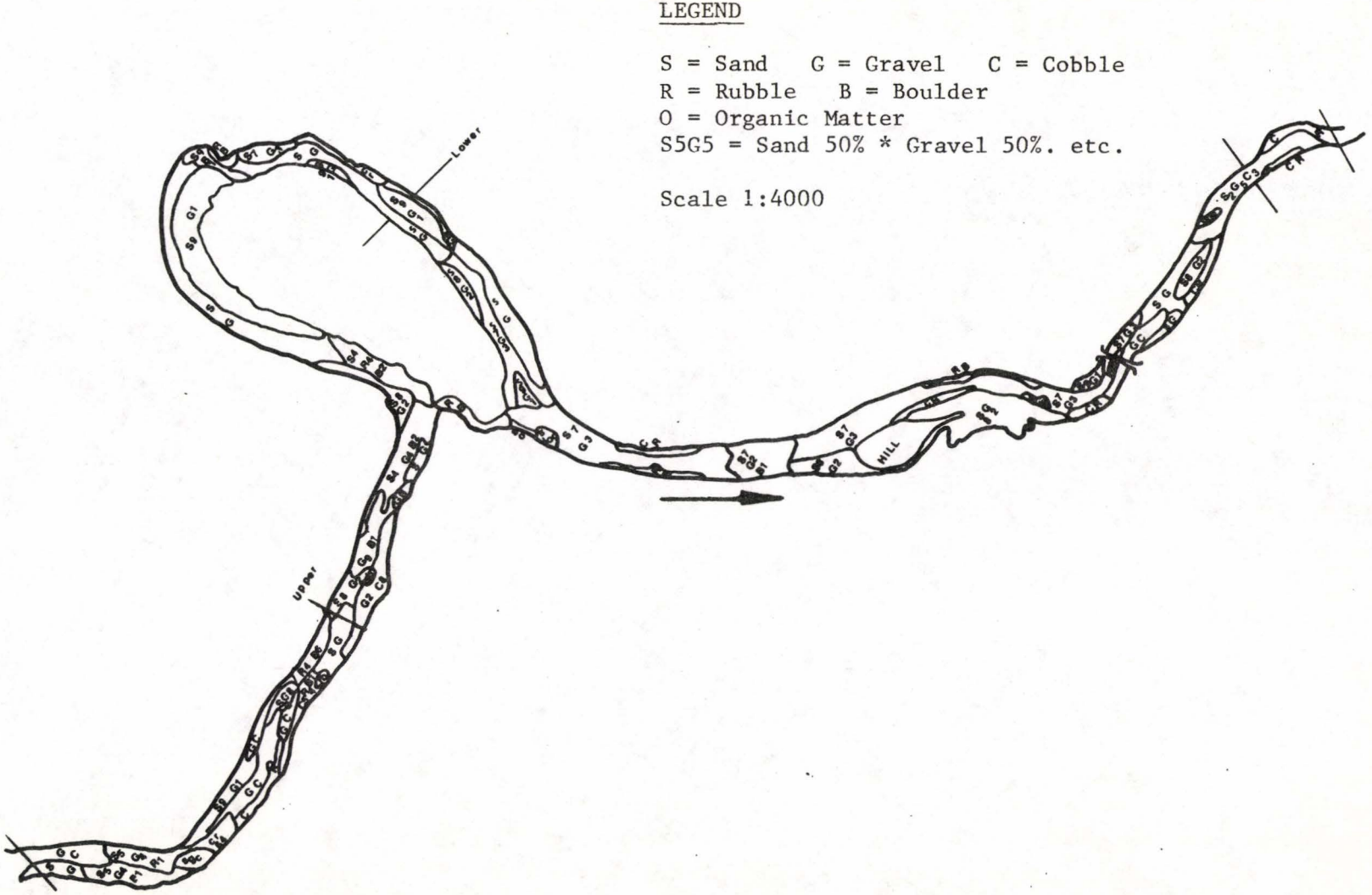


Figure 9. Planimetric map of 1976 riverbed sediments at Oxbow reach.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

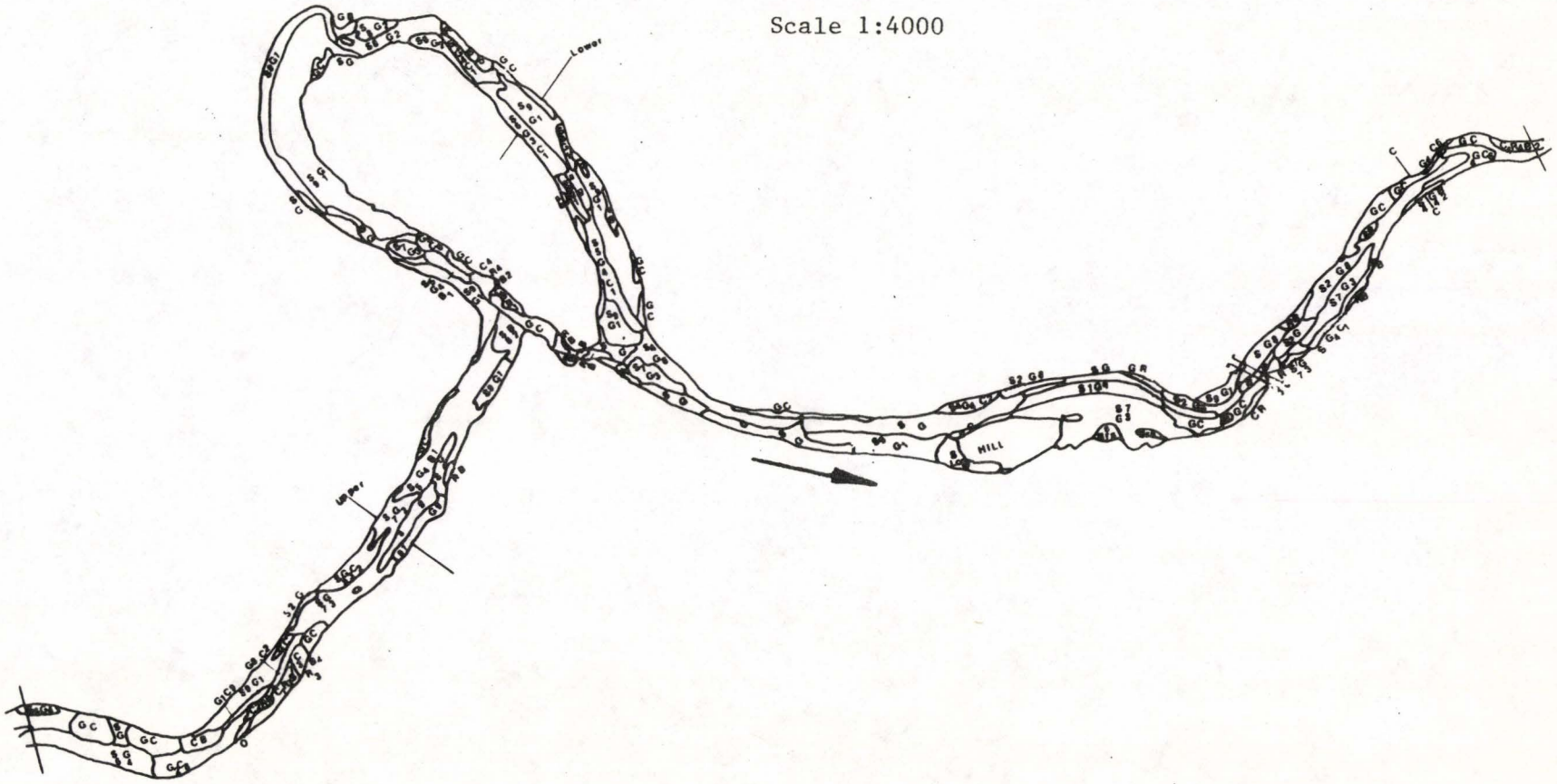


Figure 10. Planimetric map of 1979 riverbed sediments at Oxbow reach.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

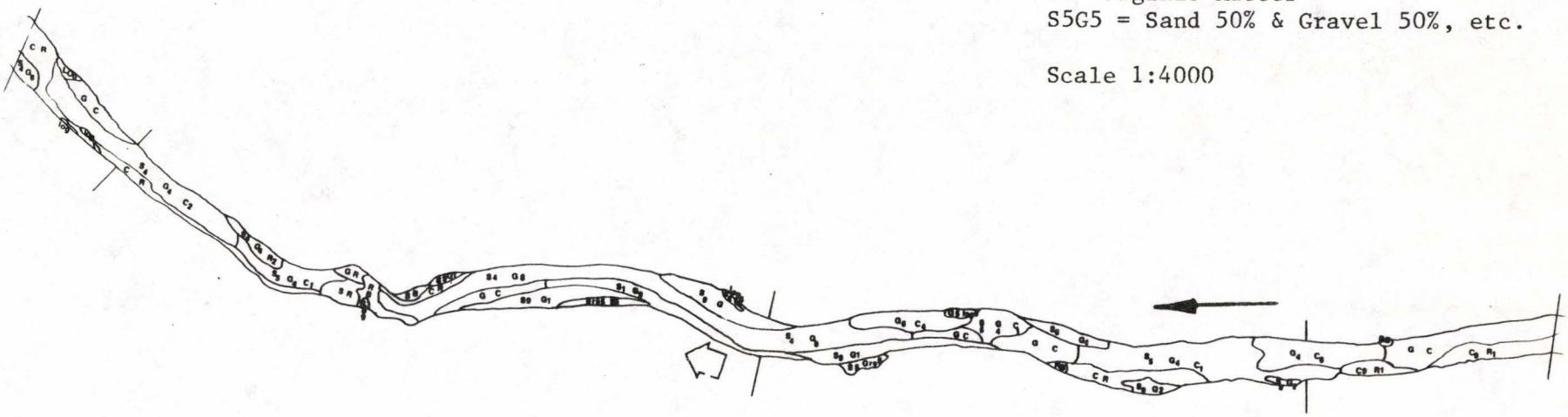


Figure 11. Planimetric map of 1965 riverbed sediments at Poverty reach.

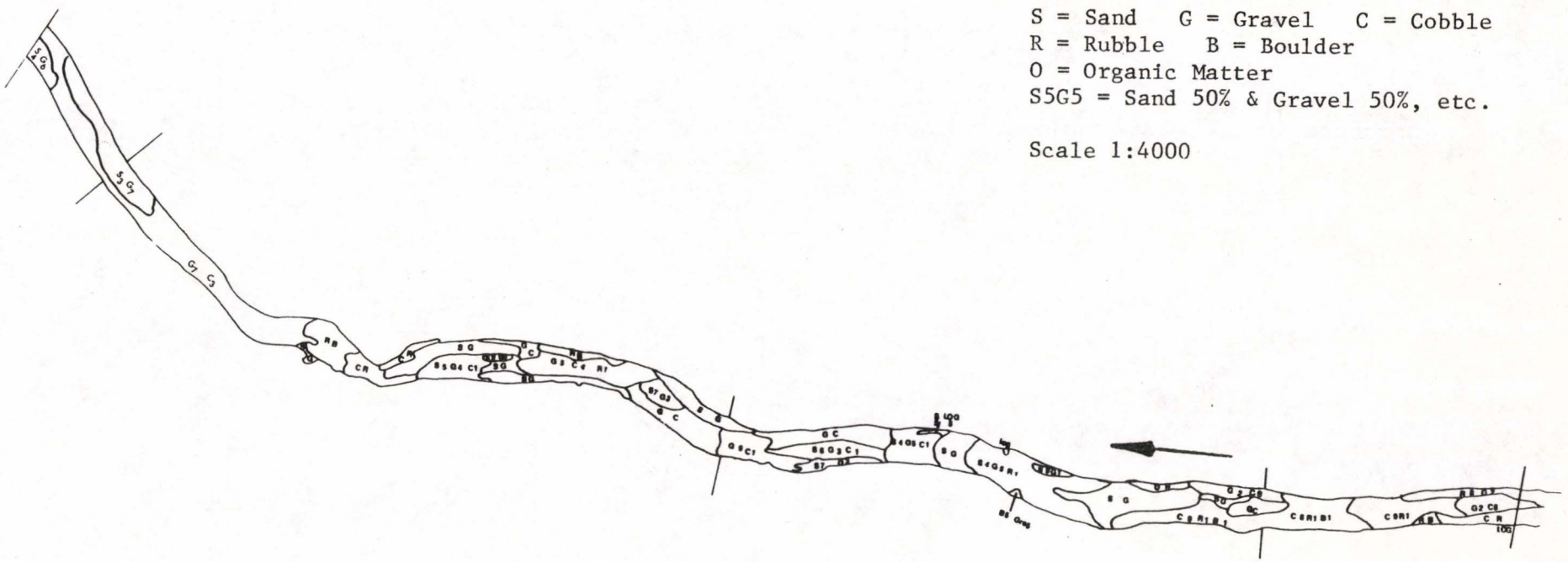


Figure 12. Planimetric map of 1972 riverbed sediments at Poverty reach.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

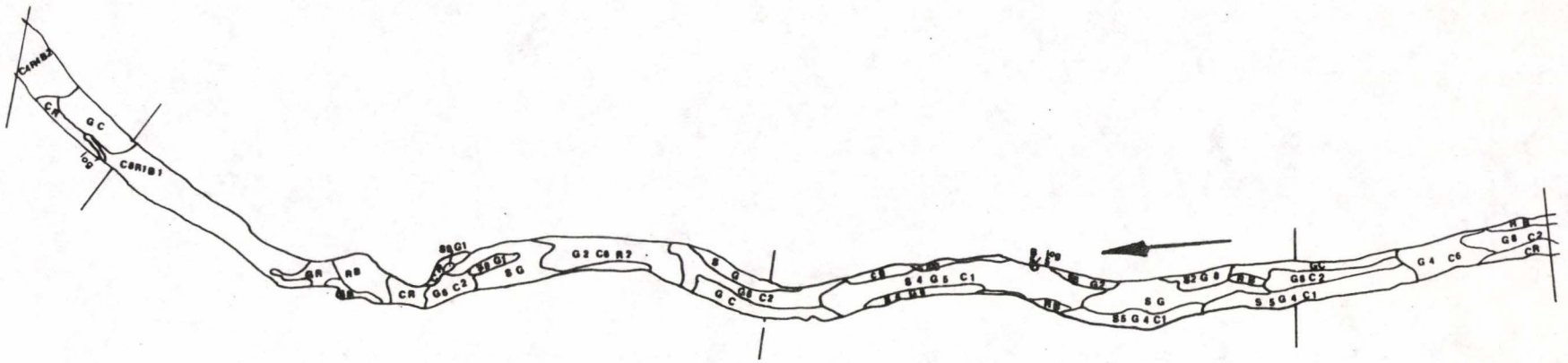


Figure 13. Planimetric map of 1976 riverbed sediments at Poverty reach.

LEGEND

S = Sand G = Gravel C = Cobble
R = Rubble B = Boulder
O = Organic Matter
S5G5 = Sand 50% & Gravel 50%, etc.

Scale 1:4000

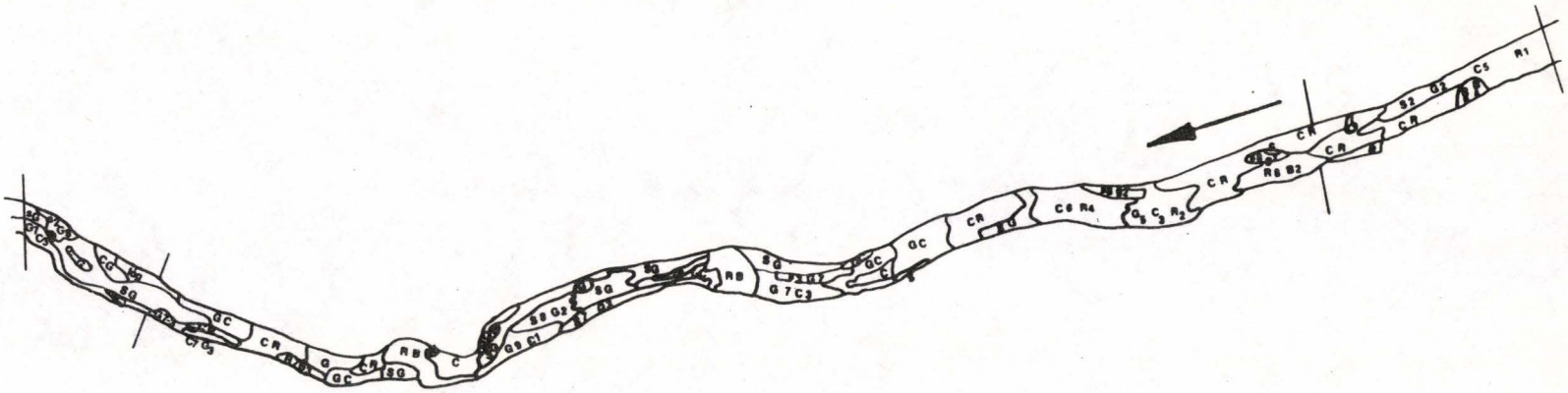


Figure 14. Planimetric map of 1979 riverbed sediments at Poverty reach.

Table 4. Area (m^2) and percentage of sediments at Krassel Hole, Oxbow and Poverty reach from 1965, 1972, 1976 and 1979 aerial photos.

Year	Sediments					Reach
	sand	gravel	cobble	rubble	boulder	
1979	20936	10982	3783	1853	1301	Krassel Hole
	53	29	10	05	03%	
1976	15139	12679	6040	4084	1554	Krassel Hole
	39	32	15	10	04%	
1972	7802	12140	10753	4324	1434	Krassel Hole
	21	33	30	12	04%	
1965	15344	16979	3167	3459	1829	Krassel Hole
	38	42	08	08	04%	
1979	48005	36486	9796	1887	2709	Oxbow Reach
	49	37	10	02	02%	
1976	47294	29575	9209	8191	5660	Oxbow Reach
	47	30	09	08	06%	
1972	37687	30693	13150	10715	6720	Oxbow Reach
	38	31	13	11	07%	
1965	39979	33164	11629	7160	2467	Oxbow Reach
	42	35	12	08	03%	
1979	8051	15314	20711	16978	5063	Poverty Reach
	12	23	31	26	08%	
1976	10911	23413	21955	6711	3266	Poverty Reach
	17	35	33	10	05%	
1972	13197	27402	18101	8236	1656	Poverty Reach
	19	40	26	12	03%	
1965	17773	23073	15494	5277	765	Poverty Reach
	28	37	25	08	02%	

Note: The area occupied by logs has not been included in the table. In view of this, total sediments area in the channel varies from year to year.

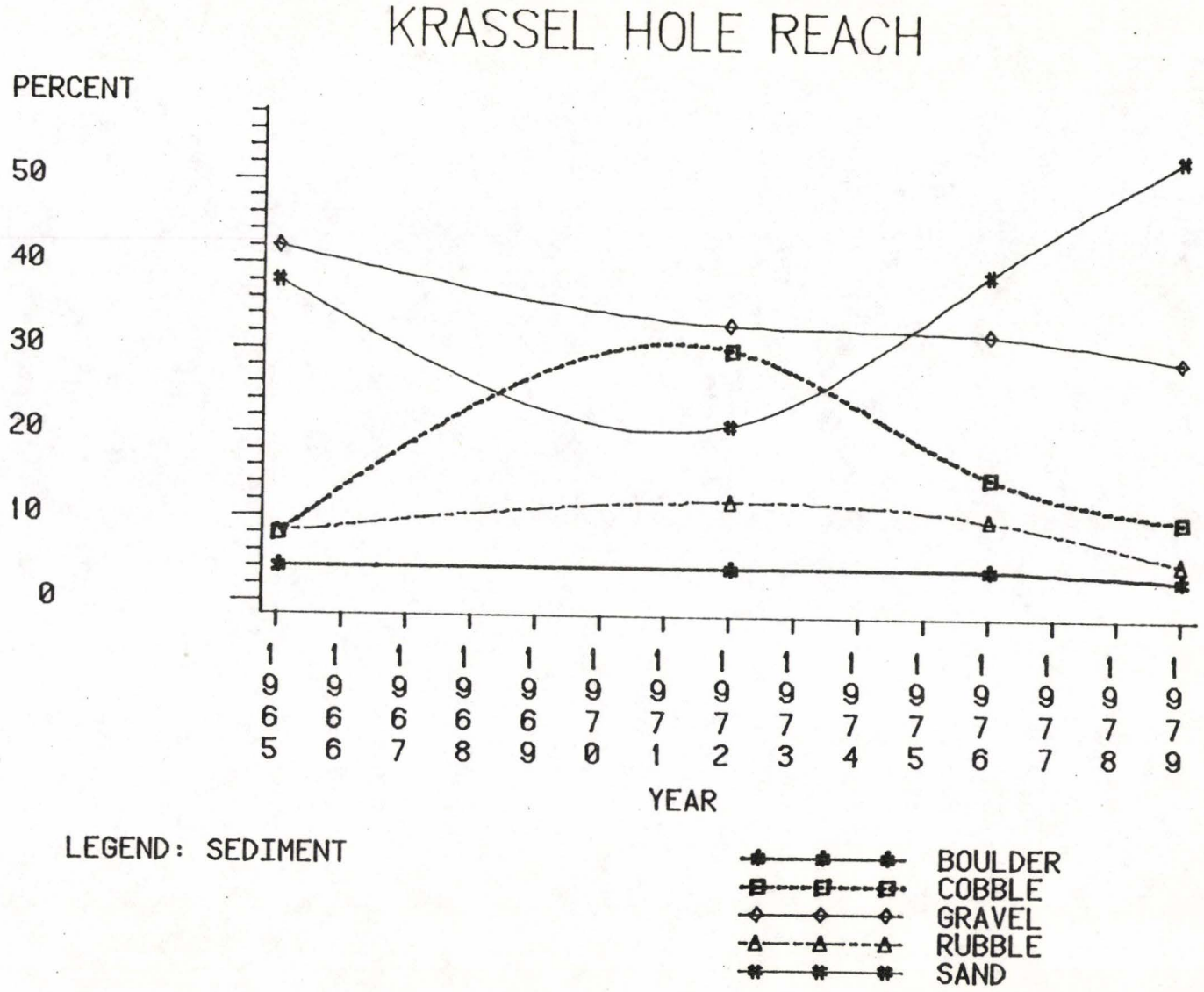


Figure 15. Time trend curves for Krassel Hole, 1965 to 1979.

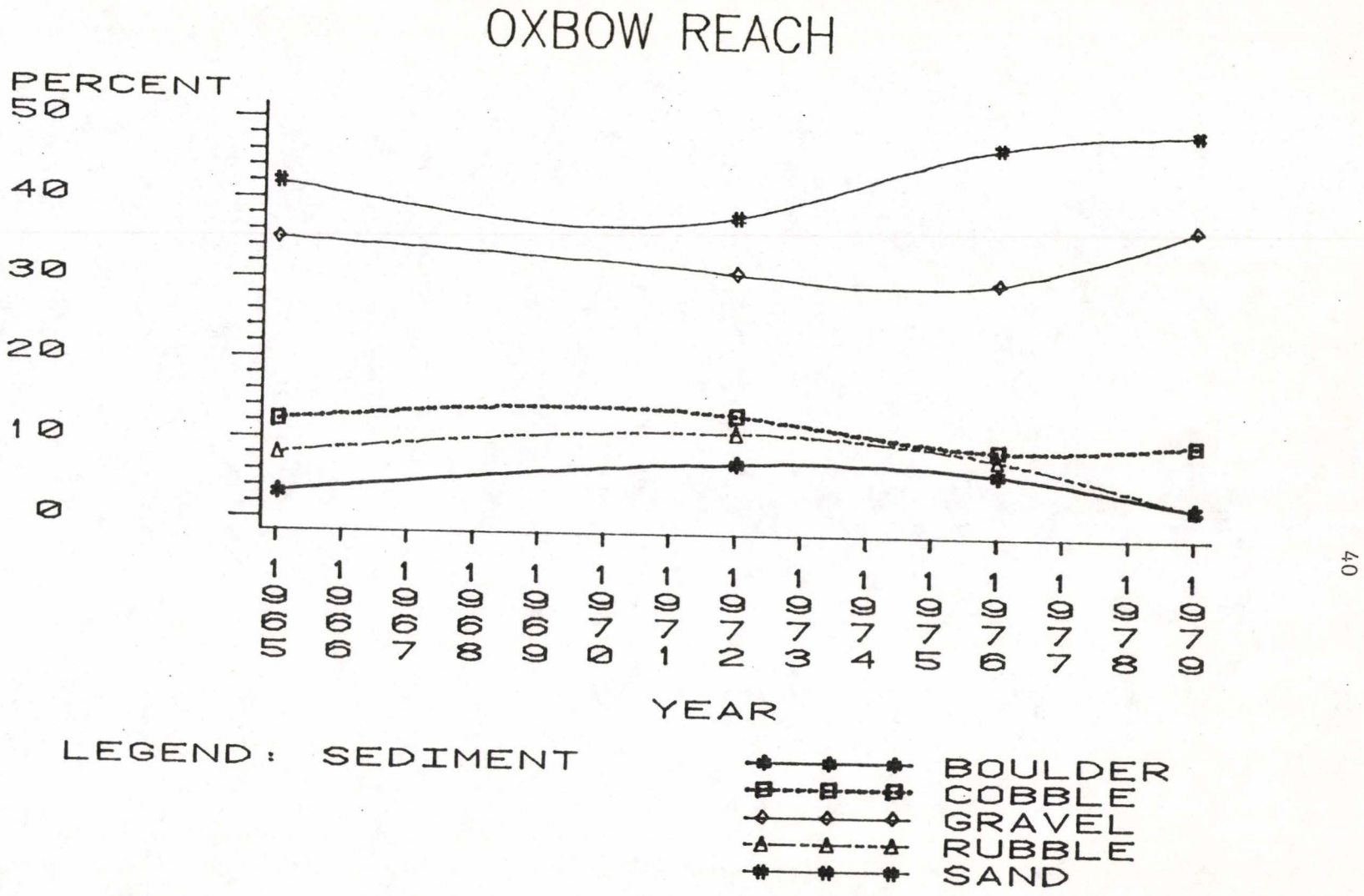


Figure 16. Time trend curves for Oxbow reach, 1965 to 1979.

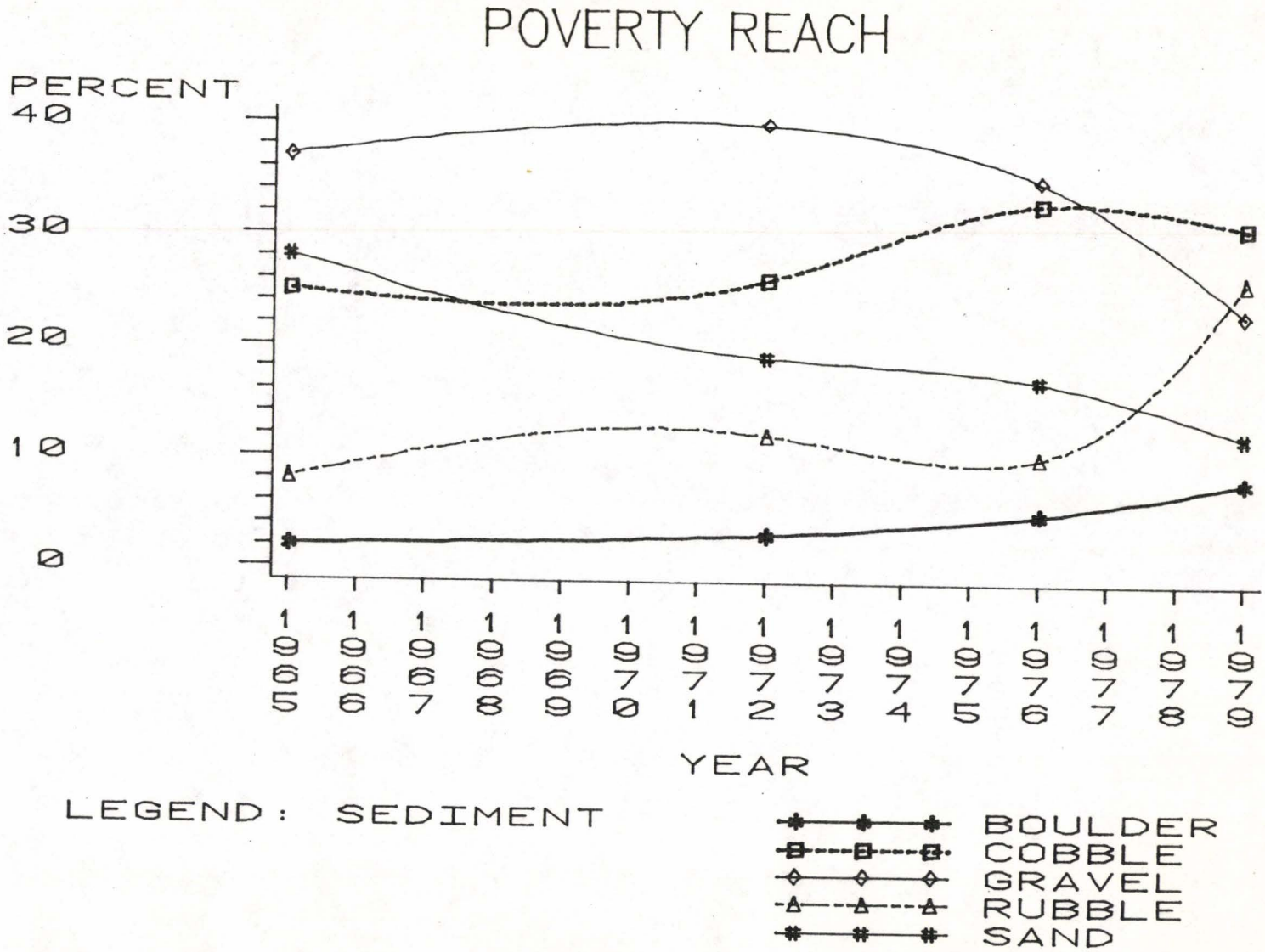


Figure 17. Time trend curves for Poverty reach, 1965 to 1979.

3.2 Comparison Between Ground Data and Airphoto Data

One of the objectives of this study is to replace the ground method of acquisition of sediment data by aerial photo methods. The credibility of air photo data can best be established by comparing the two data sets for the same time period. McCall ground data are available for years 1965, 1972, 1976 and 1979. This data consists of two parts. One is the percentage of sediments along the eight cross-sections at the three reaches. These are:

1. Krassel Hole #2
2. Krassel Hole #3
3. Upper Oxbow
4. Oxbow
5. Camp Creek at Oxbow Reach
6. Upper Poverty
7. Poverty
8. Lower Poverty

The second part contains spirit leveled heights of the riverbed along the same cross-sections. The field crew went to the site, set up the spirit level on one bank and the staff at a random point in the riverbed. Readings were taken wherever slope changed or every 4 to 5 feet, whichever was shorter. Sediment percentage was also estimated at each staff position. The total percentage at each staff position for all sediments was maintained equal to 100.

It was difficult to pick the ground located points on air photos at the time of interpretation because the ground crew did not mark each of the staff positions on the aerial photos. To overcome this difficulty the percentage of each sediment along the cross-section was computed. Equal weight was given to the linear length occupied by each sediment as well as to its percentage in that cross-section. This is explained by the following example. The same procedure was followed for all eight cross-sections. The sediment percentage was tabulated for an easy visual comparison as well as for statistical analysis.

Example

As shown in Figure 18 of the Krassel Hole planimetric map 1979:

1. The total width of the channel as measured on the airphoto = 23.0 mm. This has been entered in the tabular form under column #1, Table 5.

2. Linear length along the cross-section of polygon #1 as shown = 6.0 mm. This value has been shown in column #2.

3. The sediments contained in polygon #1 are cobble, rubble and boulder. Cobble (C) = 50%, Rubble (R) = 40%, Boulder (B) = 10%. These values were entered in column #3.

4. Sediment length occupied by "C" =

$$\frac{\text{Length of polygon along cross-section}}{\text{\# of sediments in the polygon}}$$

$\therefore$ length occupied by $C = \frac{6.0}{3} = 2.0$ mm
Similarly length occupied by R = 2.0 mm
Similarly length occupied by B = 2.0 mm
These values were shown in column #4.

5. Product of linear length and percentage of each sediment was computed: C = 2 x 50, i.e. = 100 and R = 2 x 40, i.e. = 80 and B = 2 x 10, i.e. = 20 These values were shown in column #5

6. The steps 2-5 were repeated for each polygon bisected along the cross-section in question. The total percentage for each sediment was obtained by adding values from all polygons having that sediment.

   For sand we added values as follows:

   Sand (S) = 75 + 120 + 450, i.e. = 645
   Similarly G = 75 + 80 + 50, i.e. = 205
   C = 100, i.e., only one polygon had this sediment
   R = 80, i.e., only one polygon had this sediment
   B = 20, i.e., only one polygon had this sediment

   All these values were entered in column #6

KRASSEL HOLE # 2 CROSS SECTION

YEAR 1979

Scale 1:2,000

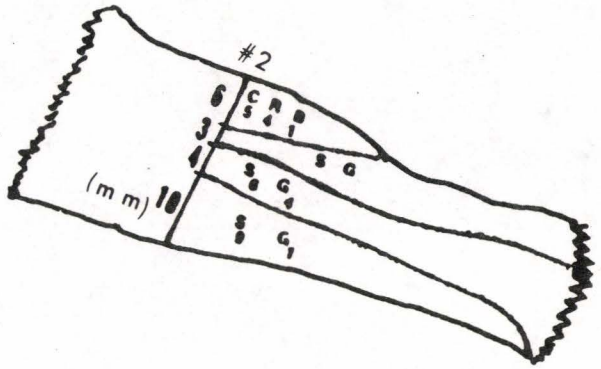


Figure 18. A portion of Krassel Hole #2 cross-section from the 1979 planimetric map.

Table 5. Procedure for computing percentage of sediments from the planimetric map. (Figures refer to Krassel Hole #2, 1979.)

1	2	3	4	5	6	7
Total width	Polygon	Sediments percentage	Sediment length	Product of length and percentage	Cumulative percentage length	Percentage of sediment
23.0	6.0	C 50	2.0	100	S = 75+120+450 = 645	S = $\frac{645}{1050}$*100 = 61.4 = 61%
(mm)	(mm)	R 40	2.0	80		
		B 10	2.0	20	G = 75+80+50 = 205	G = $\frac{205}{1050}$*100 = 19.5 = 20%
		S 50	1.5	75		
	3.0	G 50	1.5	75	C = 100	
					R = 80	C = $\frac{100}{1050}$*100 = 9.5 = 9%
		S 60	2.0	120		
	4.0	G 40	2.0	80	B = 20	R = 7.6 = 8%
		S 90	5.0	450		B = 1.9 = 2%
	10.0	G 10	5.0	50		
23.0	23.0				Total = 1050	Total = 100%

7. Percentage of individual sediment was computed:

$$\text{Sand} = \frac{\text{Sand product percentage}}{\text{Cumulated sediments percentage}} \text{ i.e. } \left(\frac{\text{Column 6}}{\text{Column 7}} \times 100\right)$$

$$\text{i.e. } \frac{645}{1050} \times 100 \text{ or } 61\%$$

Similarly for G = $\frac{205}{1050} \times 100$ i.e., = 20%

Similarly for C = $\frac{100}{1050} \times 100$ i.e. = 9%

Similarly for R = $\frac{80}{1050} \times 100$ i.e. = 8%

Similarly for B = $\frac{20}{1050} \times 100 = 2\%$

These values were entered in column #7.

8. The procedure was extended to all the eight cross-sections and results tabulated and shown in Table 6. Statistics for Table 6 data are shown in Table 7.

3.3 Riverbed Elevations and Contours

Riverbed elevation was considered an independent variable to predict changes in the channel and was also compared with ground data values. Height observations were made using a parallax bar on the photos. The ground data heights were determined with a spirit level. The data tabulated in Table 8 show a mean error of 1.7 feet and a standard deviation of 1.2 feet between the two data sets.

The reference mark (bench mark) for determining elevation was selected with the help of a topographic map. This was a large rock at Krassel Hole flush with ground level near the road above the riverbed, located very close to bench mark 3787 and shown on the USGS 7½ x 7½ Teapot Mountain Quadrangle. The B.M. is a permanent rock and our assumption was that there has been no disturbance of any kind to this rock since 1946. Since the reference mark was designated 100 feet, all riverbed elevations are less than 100.

Table 6. Percentage comparison of sediments, airphoto versus McCall ground data for the year 1979 for Krassel Hole, Poverty Reach and Oxbow Reach.

	Air Photos					Ground Data				
Reach	sand	gravel	cobble	rubble	boulder	sand	gravel	cobble	rubble	boulder
Krassel Hole #2	61	20	09	08	02	71	26	03	00	00
Krassel Hole #3	46	44	08	02	00	63	25	10	02	00
Upper Oxbow	40	50	10	00	00	30	54	16	00	00
Oxbow	62	24	14	00	00	89	09	00	02	00
Camp Creek	50	33	16	00	03	63	15	22	00	00
Upper Poverty	20	43	20	10	07	30	53	17	00	00
Poverty	67	23	10	00	00	79	19	01	00	00
Lower Poverty	58	25	17	00	00	72	06	22	00	00

Table 7. Means, standard deviation, and other statistics of Table 6 data.

Variable	N	Mean	Standard deviation	Minimum value	Maximum value	Standard error of mean
Air Photo						
Sand	8	50.5	15.3	20.0	67.0	5.4
Gravel	8	32.8	11.5	20.0	50.0	4.1
Cobble	8	13.0	4.4	8.0	20.0	1.5
Rubble	8	2.5	4.1	0.0	10.0	1.4
Boulder	8	1.5	2.5	0.0	7.0	0.9
Ground Data						
Sand	8	62.1	21.5	30.0	89.0	7.6
Gravel	8	25.9	18.4	6.0	54.0	6.5
Cobble	8	11.4	9.2	0.0	22.0	3.2
Rubble	8	0.5	0.9	0.0	2.0	0.3
Boulder	8	0.0	0.0	0.0	0.0	0.0

Table 8. Elevations from aerial photos and ground data for 1979 at the eight cross-sections (McCall data). (See notes below.)

Location (cross-section)	Elevations of riverbed (feet)						
	Aerial photo positions across the riverbed						
	1	2	3	4	5	6	7
Krassel Hole Cross-section #2	100.0	93.1	93.9	92.7	91.8	93.5	94.7
Krassel Hole Cross-section #3	100.0	90.2	89.8	89.4	89.8	89.4	89.4
Upper Oxbow Cross-section	100.0	91.1	91.8	90.8	90.4	89.4	96.5
Lower Oxbow Cross-section	100.0	93.3	93.3	92.6	95.4	95.7	98.9
Camp Creek Cross-section	100.0	89.9	89.2	87.5	90.6	87.8	95.8
Upper Poverty Cross-section	100.0	93.0	89.9	89.4	88.5	88.5	89.9
Lower Poverty Cross-section	100.0	89.4	88.5	88.1	90.3	90.3	97.8
Poverty Cross-section	100.0	93.4	92.1	93.0	92.5	92.1	97.4
	Ground (McCall) positions across the riverbed						
	1	2	3	4	5	6	7
Krassel Hole Cross-section #2	100.0	93.1	92.1	91.5	90.3	91.1	93.7
Krassel Hole Cross-section #3	100.0	91.7	91.7	91.8	92.4	92.8	97.8
Upper Oxbow Cross-section	100.0	91.4	90.5	90.7	90.9	89.0	96.9
Lower Oxbow Cross-section	100.0	93.0	92.3	92.1	93.6	95.6	98.4
Camp Creek Cross-section	100.0	93.3	91.3	92.3	94.6	94.6	96.1
Upper Poverty Cross-section	100.0	91.7	91.0	91.3	91.3	91.4	91.2
Lower Poverty Cross-section	100.0	89.7	89.4	89.8	90.9	91.6	97.2
Poverty Cross-section	100.0	94.6	89.7	91.3	91.4	92.7	97.5

Notes:

1. Position 1 was made identical with the target mark appearing on the 1979 aerial photograph. It was used as a reference point and its ground height was arbitrarily assumed to be equal to 100.

2. Positions 2, 3, 4, 5 and 6 were selected in the riverbed and were identified on all aerial photos. Position 7 was sited on the far bank, outside the riverbed.

3. The ground data values were obtained from the McCall data list. The point that was found to be nearest in position to the airphoto point was picked up and its elevation has been listed for comparison.

In addition to the above, ground targets as appearing in aerial photographs of 1979 have been used as bench marks for each of the eight cross-sections. The heights of all the eight cross-sections have been tabulated for comparison with ground heights.

Because tilt was greater than 3° in the photographs, a slightly oblique view rather than a truly vertical record has been presented. Due to this, most of the images have been displaced radially toward the isocenter on the upper side of a tilted photograph and radially outward or away from the isocenter on the lower side. The isocenter may be defined as a point occurring at the hinge formed by the tilted negative and an imaginary horizontal plane. Along the axis of tilt, there is no displacement relative to an equivalent untilted photograph. The course of the South Fork of the Salmon River contained in these photographs is zigzag. The points selected for height measurements in the river channel are on either side of the tilt axis and errors due to tilt did not compensate.

The exact angle and direction of tilt are rarely known to the interpreter and precise location of the isocenter is therefore a tedious process. It was assumed that the isocenter coincides with the easily located principal point. This assumption became a most significant source of error in the parallax measurements. To overcome this, we had adjusted the airphoto derived heights with the known ground elevations by using a linear regression procedure. Four spirit leveled points on the ground were identified on the airphotos and heights determined by making parallax measurements. The airphoto heights were treated as the dependent variable and the spirit leveled heights as the independent variable. The regression parameters were obtained and subsequently used

to predict the ground heights from the airphoto derived heights. The contour map from 1979 air photographs was based on the adjusted heights and is shown in Figure 19. The datum as discussed elsewhere was set arbitrarily equal to 100 and the riverbed elevations were based on the same. The elevations were not adjusted to the topographic map heights and as such are not related to the surrounding contours. These are only relatively correct and depict the channel configuration. In view of the tilt distortions, contour maps for the remaining years were not prepared and computer analysis of storage differences was not attempted.

3.3.1 Cross-section profiles

Ground and air photo elevations have been graphically compared for year 1979 using the PLOTALL computer program. The cross-section of the riverbed has been used as the x variable and all elevations as the y variable. The two data sets are distinguished by different symbols and explained in a legend. The program used quadratic interpolation and results are attached for all the eight cross-sections in the succeeding figures. The agreement between ground and air photo elevations was found to be very close. The plots are shown in Figures 20-27.

3.4 Statistical Analysis

3.4.1 All three reaches

It will be noted from Table 9 that there was no statistically significant variability for particle size distribution of sediments during the period of time from year 1965 to 1979. However, the three reaches differed in regard to the composition of sediments between one and the other. In other words, particle composition at Oxbow was different than at Krassel Hole and Poverty Reach.

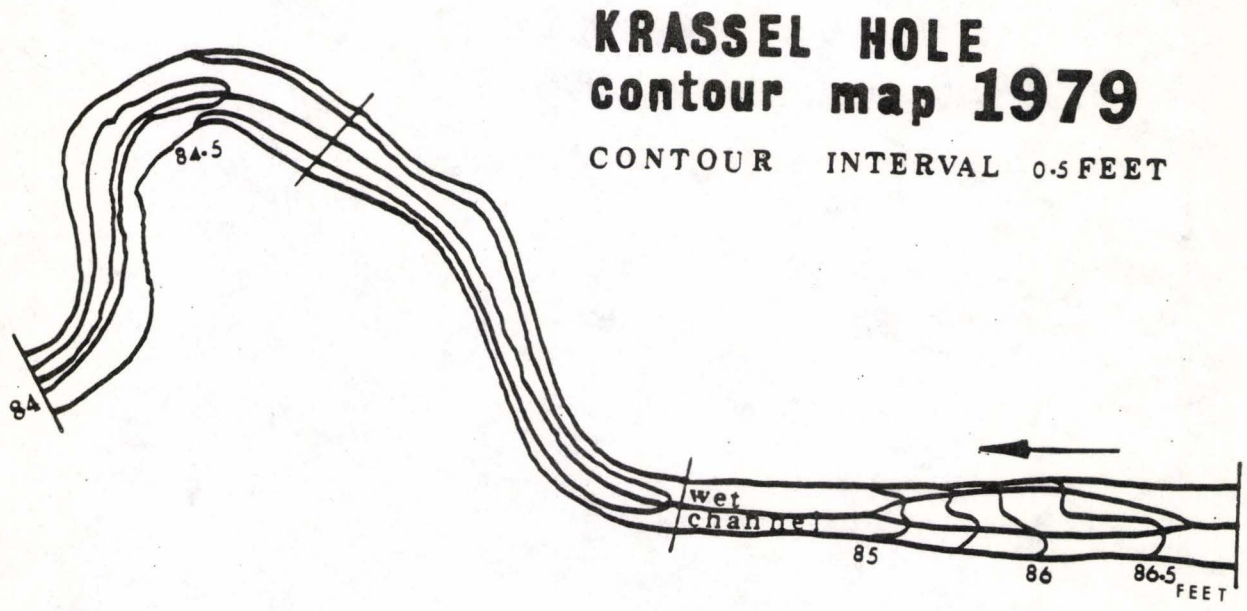


Figure 19. Krassel Hole reach contour map based on heights measured from aerial photographs of 1979.

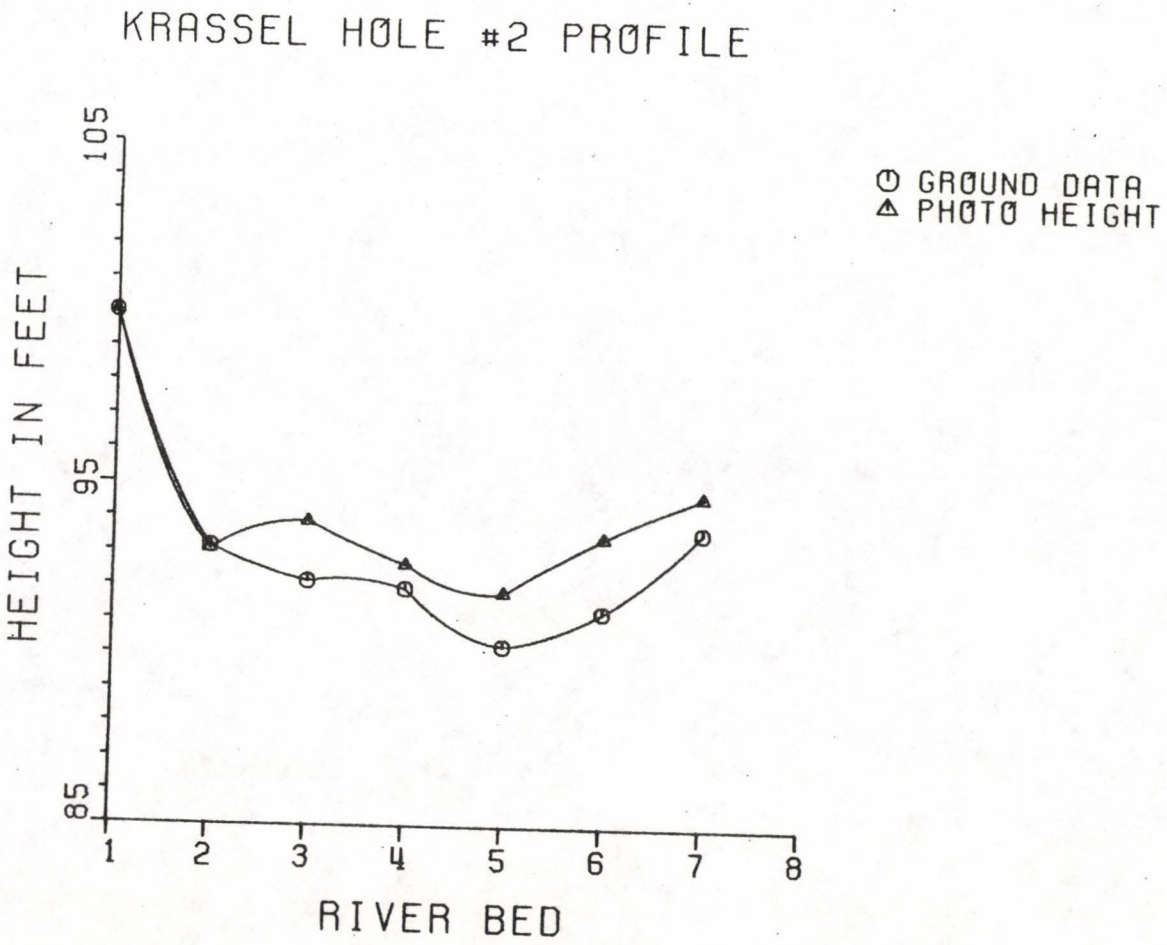


Figure 20. Ground elevations versus aerial photo elevations at Krassel Hole #2 cross-section.

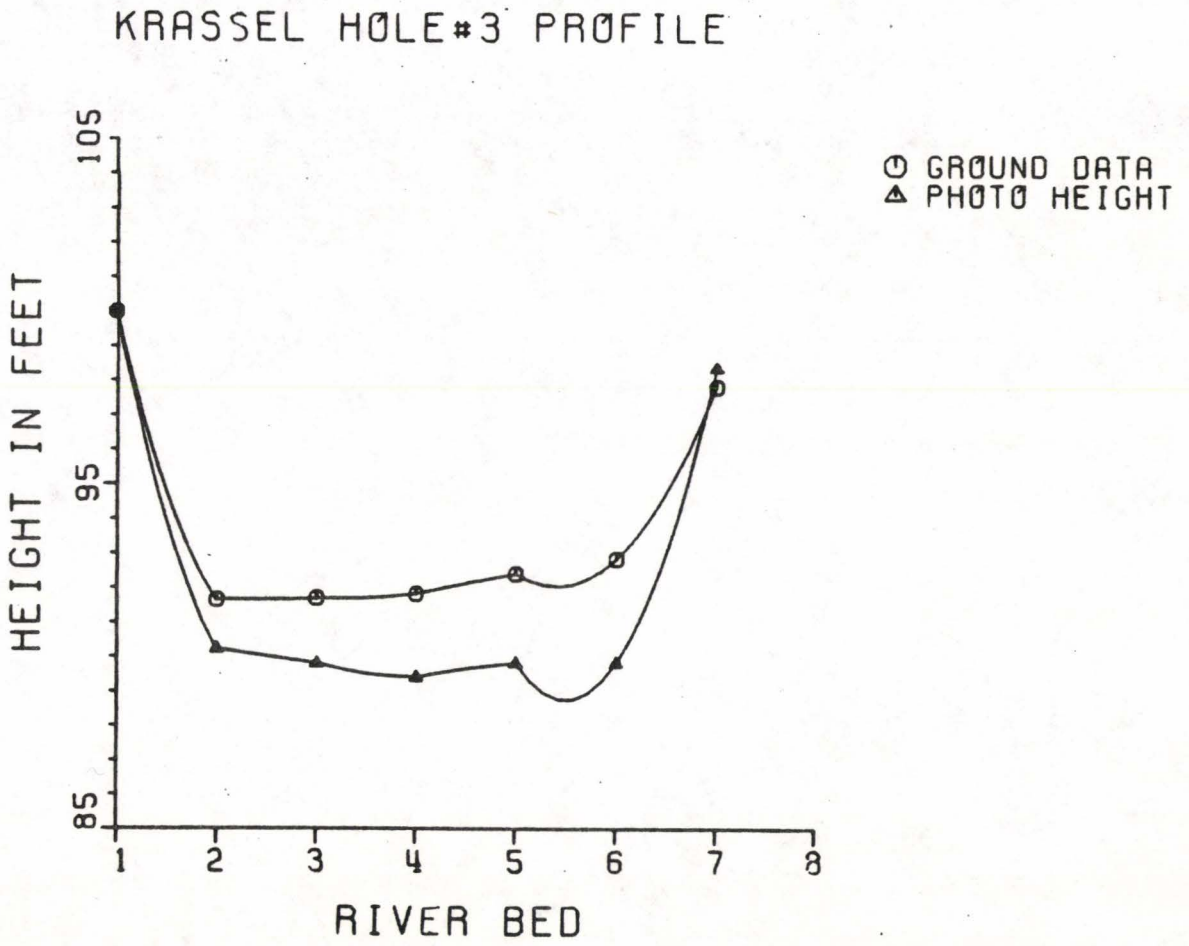


Figure 21. Ground elevations versus aerial photo elevations at Krassel Hole #3 cross-section.

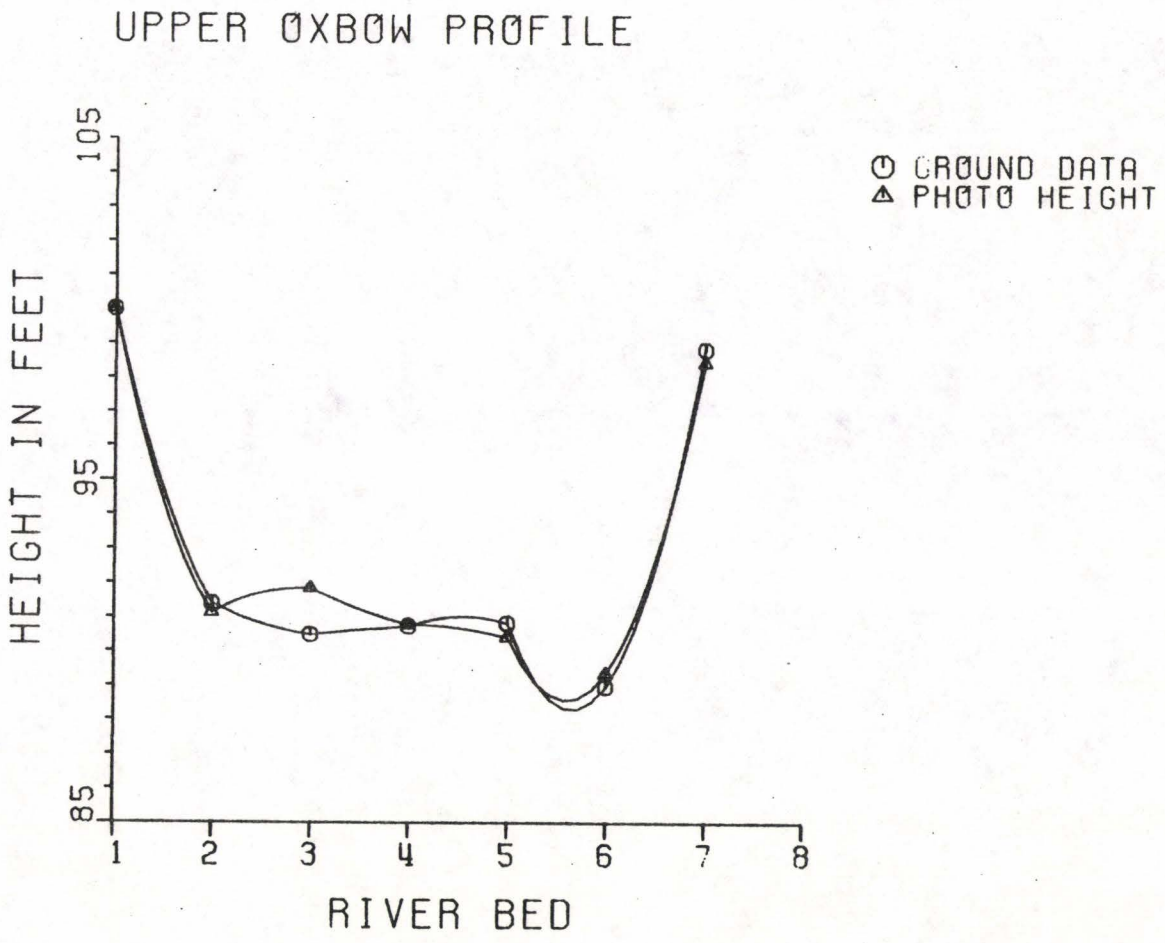


Figure 22. Ground elevations versus aerial photo elevations at Upper Oxbow cross-section.

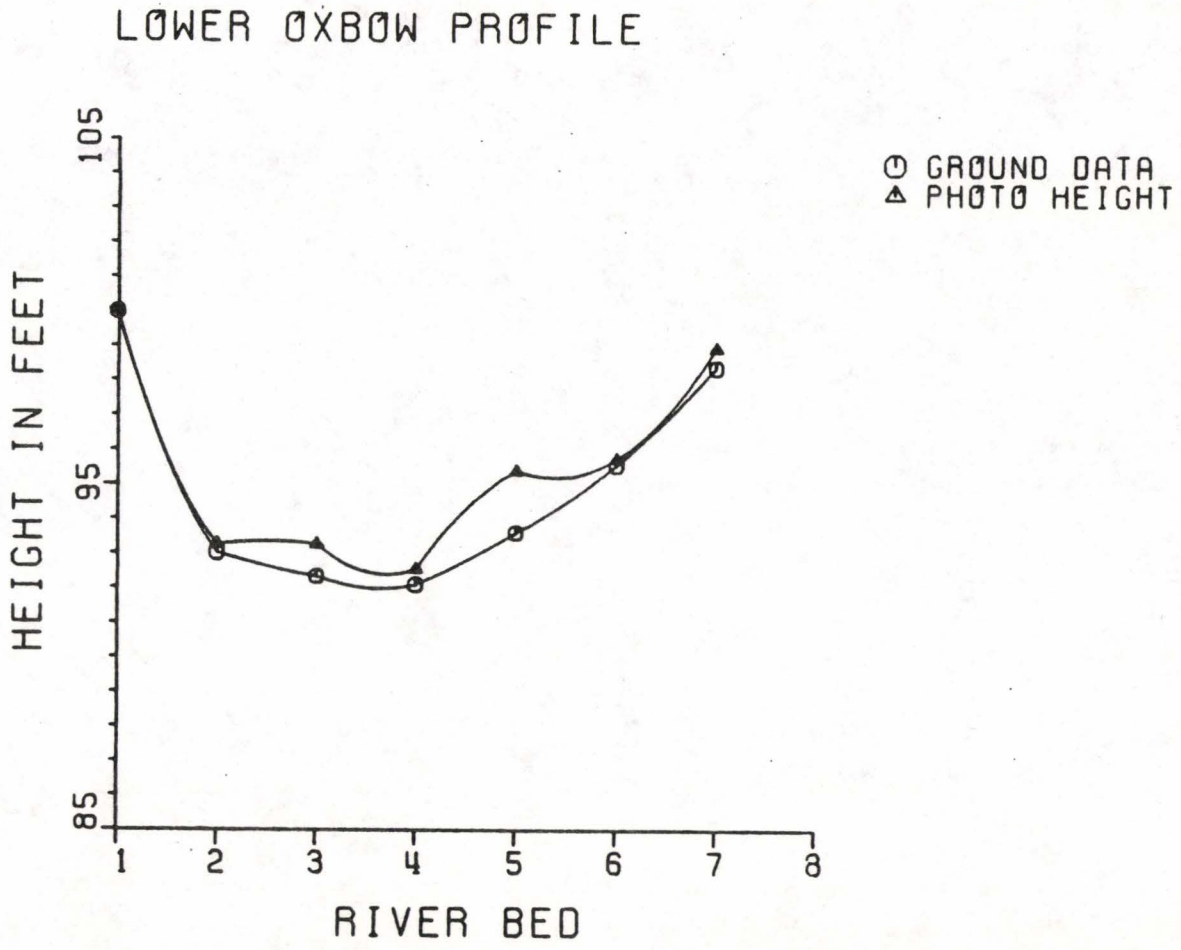


Figure 23. Ground elevations versus aerial photo elevations at Lower Oxbow cross-section.

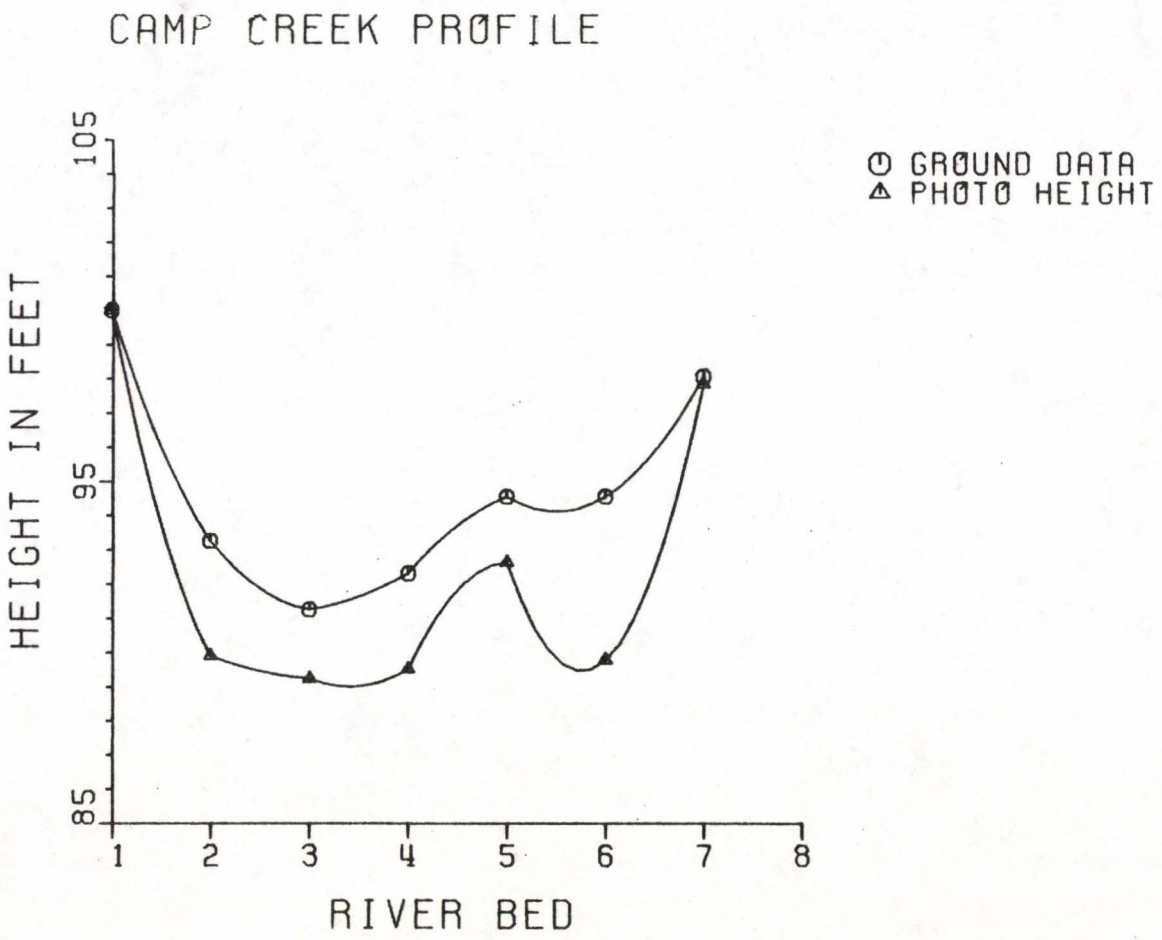


Figure 24. Ground elevations versus aerial photo elevations at Oxbow Camp Creek cross-section.

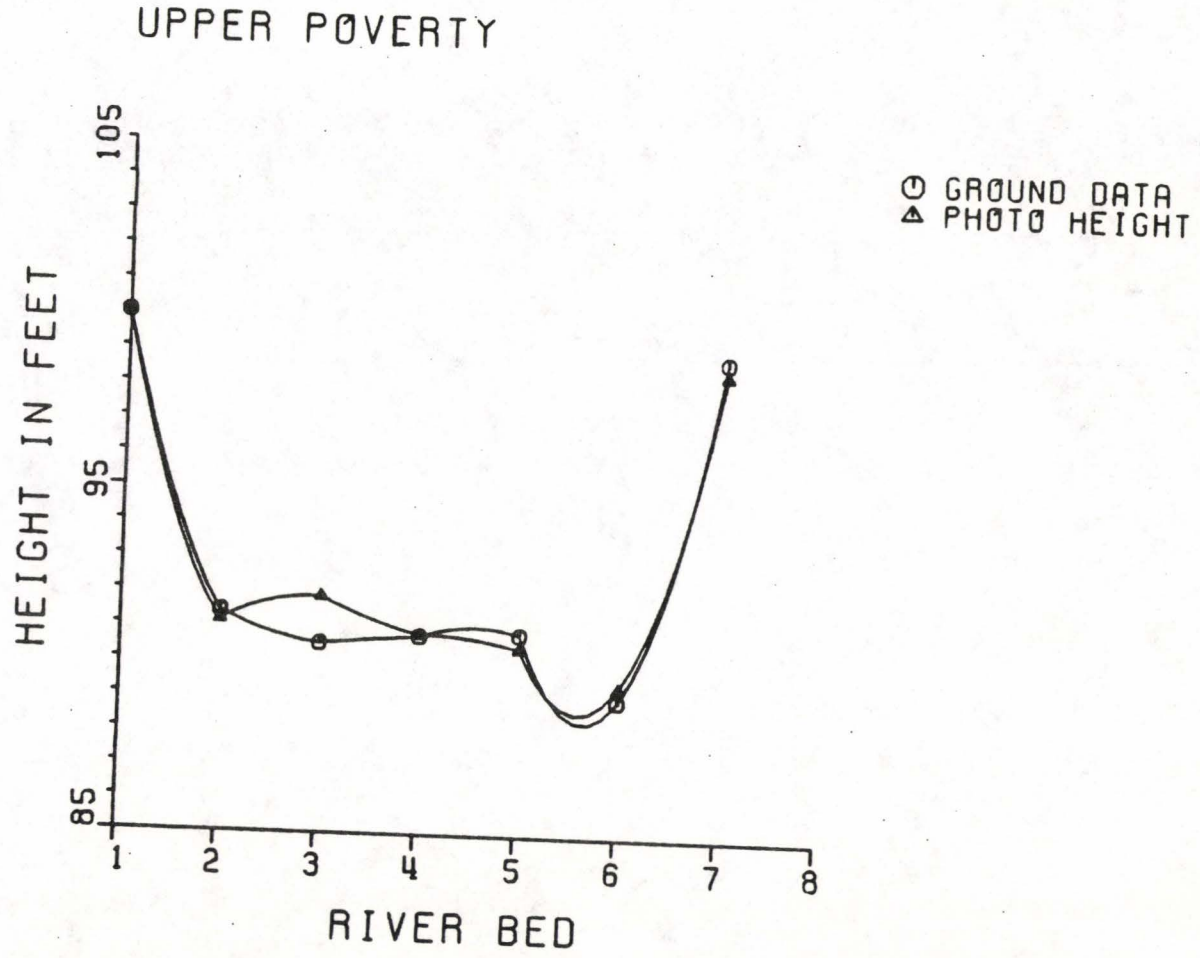


Figure 25. Ground elevations versus aerial photo elevations at Upper Poverty cross-section.

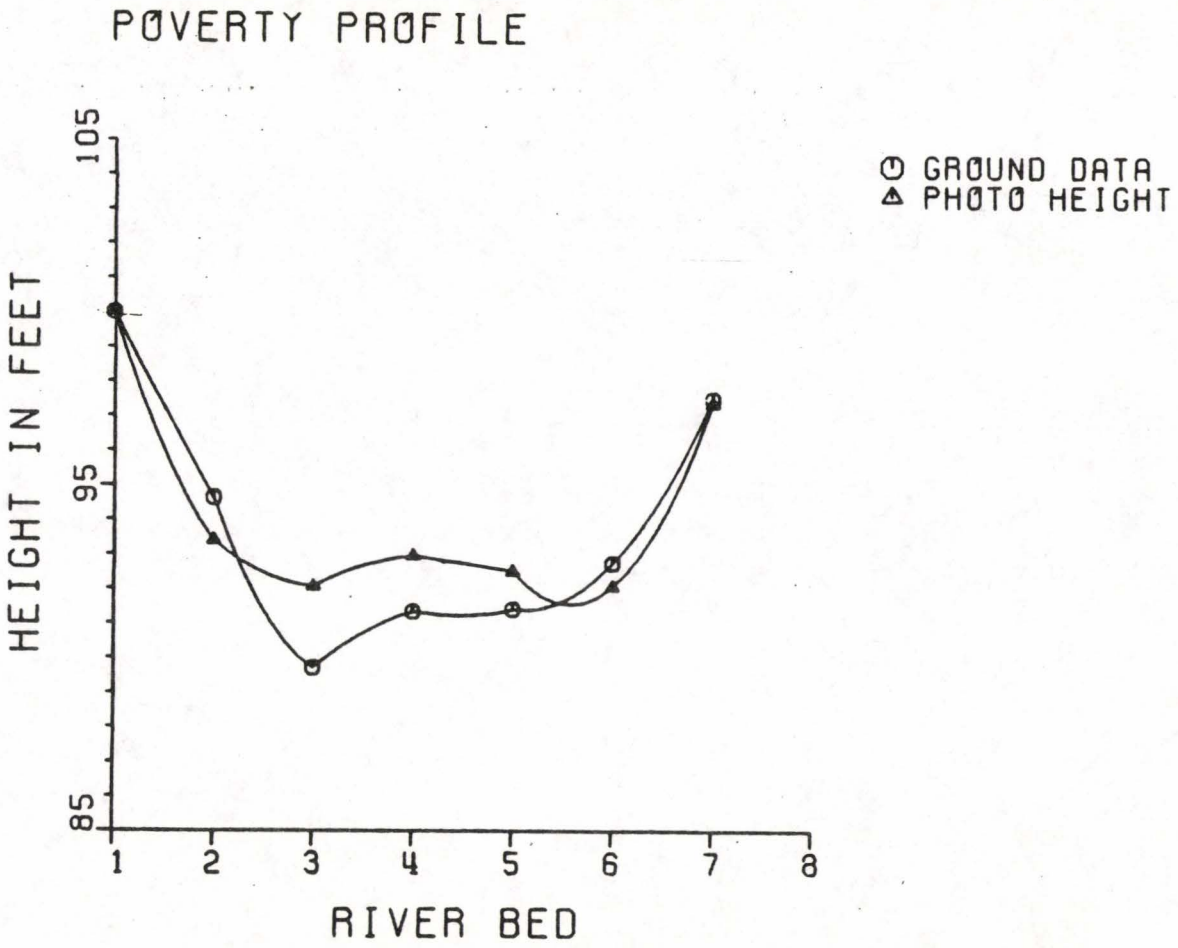


Figure 26. Ground elevations versus aerial photo elevations at Poverty cross-section.

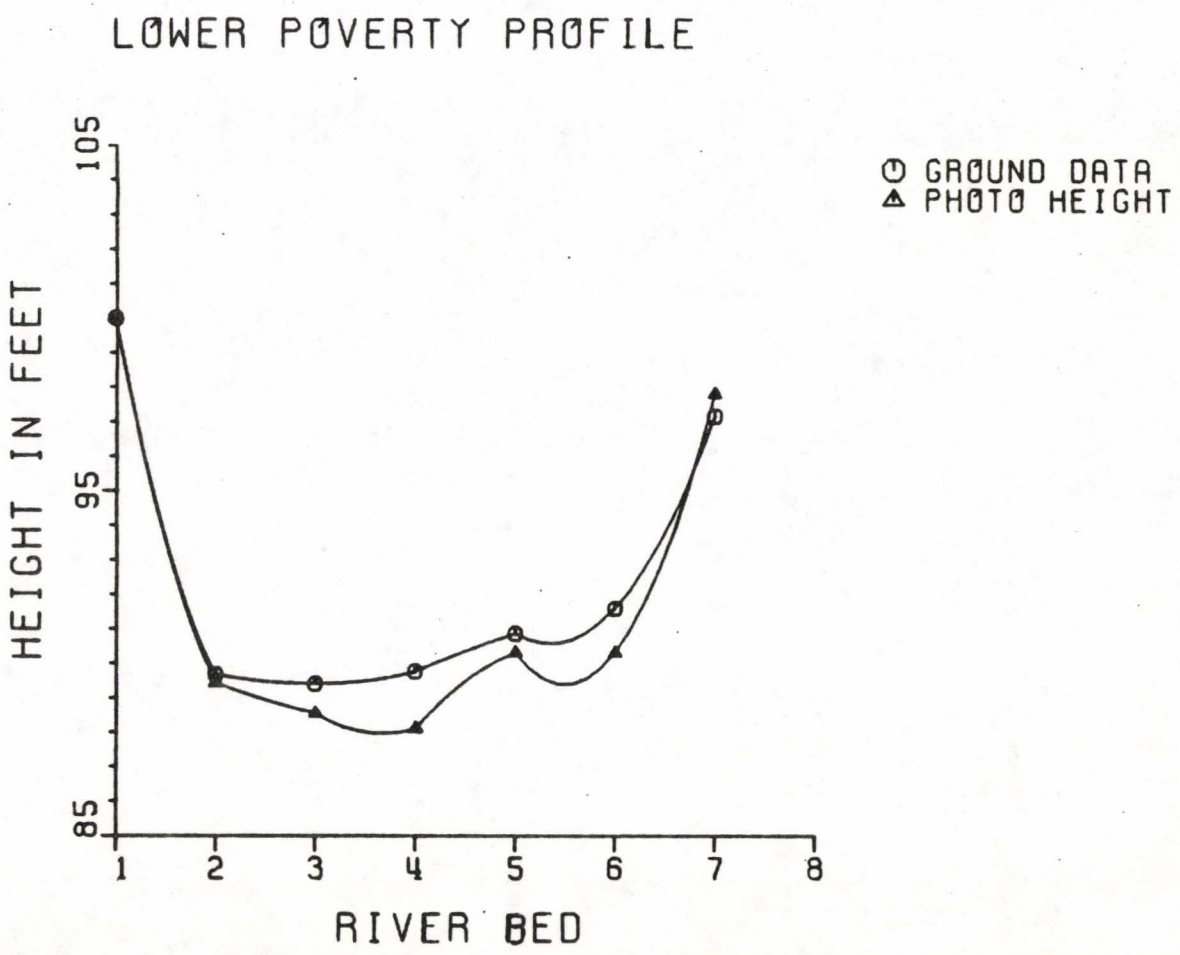


Figure 27. Ground elevations versus aerial photo elevations at Lower Poverty cross-section.

Table 9. Analysis of variance on interpreted airphoto data from 1965, 1972, 1976, and 1979 for Krassel Hole, Poverty, and Oxbow Reaches.

Source of variation	d.f.	Mean Squares				
		Sand	Gravel	Cobble	Rubble	Boulder
years	3	83.417	37.555	35.0000	8.222	2.306
sites	2					
error	6	677.083*	0.583	337.750*	50.250	0.750
total	11					
R^2		.770	.450	.760	.400	.210

* P < .05; ** P < .01

No sediment showed any significant changes from 1965 to 1979. However, all three sites differed significantly from one another in mean sand and cobble distributions.

3.4.2 Eight cross-sections

In the second part "McCall" sediment data of eight cross-sections were used: two cross-sections at Krassel Hole, three cross-sections at Oxbow Reach, and three cross-sections at Poverty Reach. The cross-sections and year were treated as independent variables and sediments as dependent variables. The data were used for the same period of 1965 to 1979. The use of cross-sections added randomness to the statistical analysis and provided higher degrees of freedom.

The results (Table 10) are similar. No statistically significant variability in particle size distribution of sediments was noticed over the period of time from 1965 to 1979. The variability of sediment composition among the eight cross-sections was confirmed. In other words, the sediment composition in the riverbed in any of the reaches differed from point to point, while the change in this composition over a period of time was not found to be statistically significant.

3.4.3 Ten transects based on Boise data

In the third part we used the data from "Boise." In this case 10 transects were selected in each reach compared to two or three in the previous analysis. This was done in the case of Krassel Hole and Poverty Reach. Oxbow Reach was omitted because there was no ground data available. The results of this part will be discussed under the Modified Design chapter. Figures 28 and 29 show the 20 transects at Krassel Hole and Poverty reaches.

Table 10. Analysis of variance on airphoto data from the eight cross-sections of the three reaches from 1965 to 1979.

Source of variation	d.f.	Mean Squares				
		Sand	Gravel	Cobble	Rubble	Boulder
years	3	105.531	94.115	24.697	14.708	2.542
cross-sections	7	814.745**	279.495*	358.827	31.339	2.768
error	21	50.100	53.320	52.980	17.540	2.180
total	31					
R^2		.850	.670	.700	.420	.370

* P < .05; ** P < .01

No sediment showed any significant change in composition from 1965 to 1979. However, all eight cross-sections had significant variations in sand and gravel distributions among themselves.

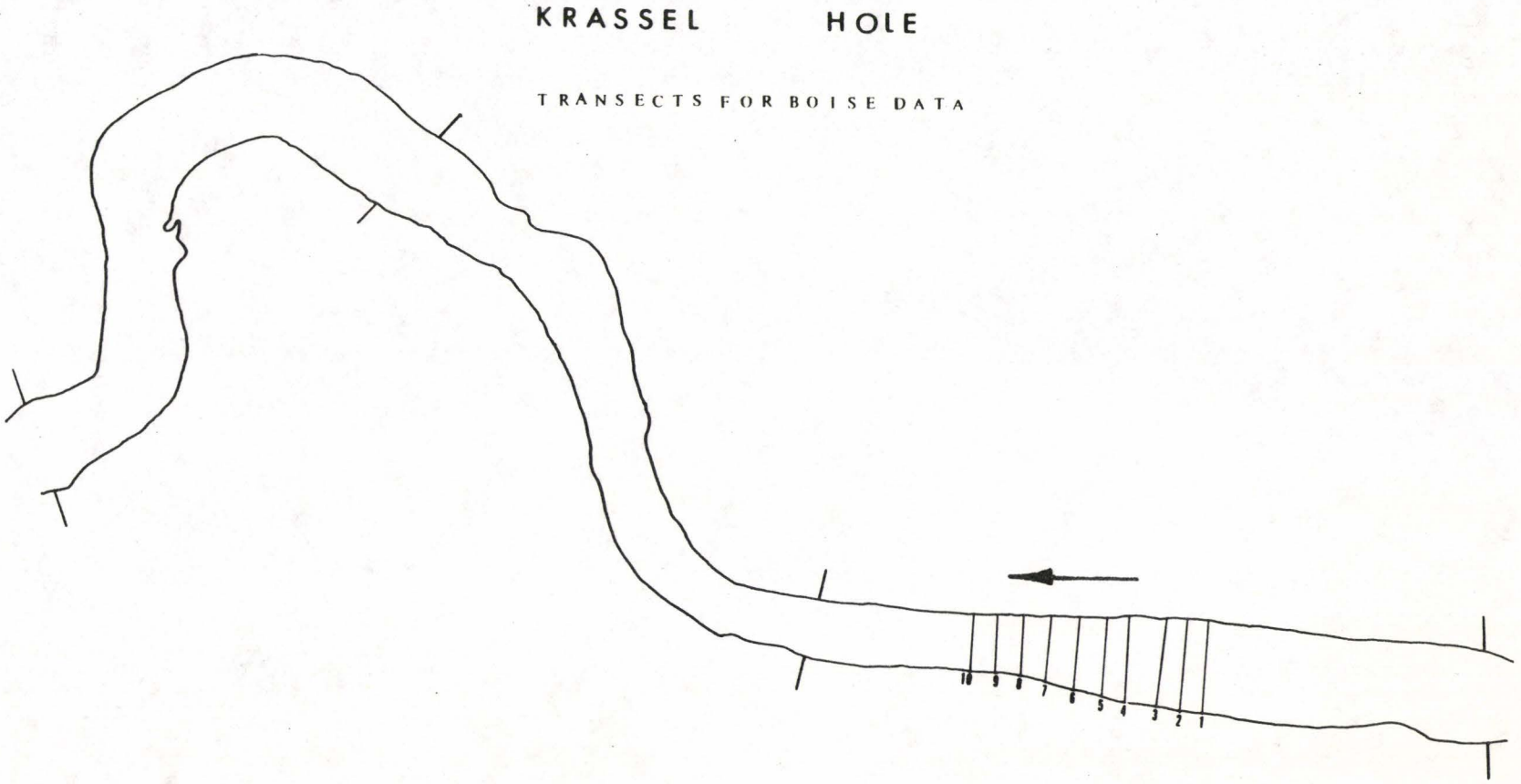


Figure 28. Transects at Krassel Hole (Boise ground data).

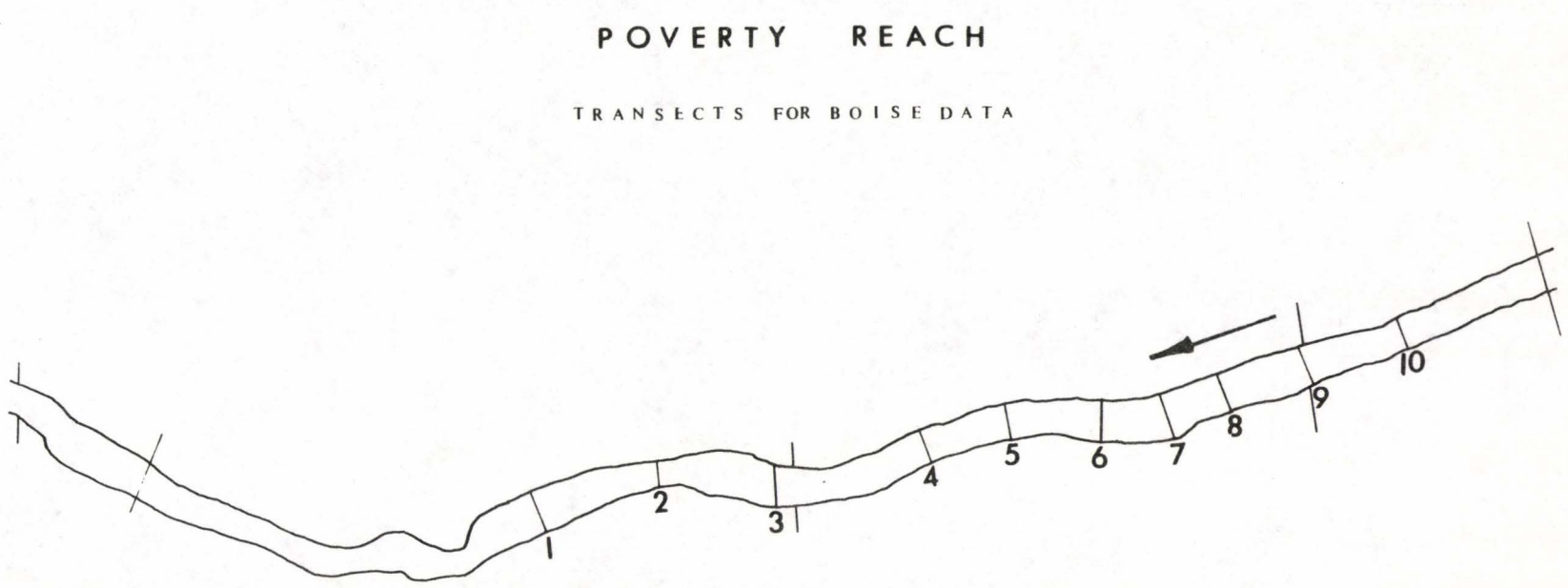


Figure 29. Transects at Poverty (Boise ground data).

3.5 Modified Design

To this point the ground data used for the comparison with aerial photo data came from McCall data. Under the modified design the Boise data has been used for comparison with aerial photo data. The data covered Krassel Hole and Poverty Reach for year 1972, 1976 and 1979. The ground data consisted of sediment percentages along the ten transects, and no elevation data was collected on the ground. The ground positions of the transects were marked on the aerial photographs and the same transects were measured for each year.

Under this approach, cobble was dropped and the sizes of rubble and boulder were modified. The following four sediments and their sizes were surveyed:

Sand - less than 0.25 inch
Gravel - between .25 and 4.0 inches
Rubble - between 4.0 and 12.0 inches
Boulder - greater than 12.0 inches

The air photo data and ground data are compiled and a statistical analysis carried out. Two sets of air photo interpreted data were obtained to provide more degrees of freedom.

The modified model provided another datum to compare the air photo and ground data results. The air photos were interpreted and sediments detected along the 10 transects that were marked on the air photos. The same set of air photos and instruments were used. Therefore, any variability due to these components was eliminated. The interpretation commenced with Krassel Hole transects and work was replicated. However, the replication was not done simultaneously but was done after a gap of several days so as to minimize any bias in the interpretation. The photographs of years 1965, 1972, 1976 and 1977 were used.

The results were compiled and tabulated in the same manner as was done in the case of eight cross-sections using McCall data set. Weights were assigned to linear length and percentage of sediments along the transect.

The data have been tabulated for a visual comparison (Appendix Tables 1-4). The mean and standard deviations have also been computed and listed in Table 11. Since ground data were not available for the year 1965, the comparison applies to 1972, 1976 and 1979 only.

3.5.1 Statistical analysis of airphoto data

This statistical analysis consisted of two parts. The first one was based on air photo data of 1965, 1972, 1976 and 1979. The results of the analysis of variance have been listed separately, for Krassel Hole in Table 12 and Poverty Reach in Table 13. At Krassel Hole, no significant changes have been noticed in the case of sand and rubble. Gravel has undergone significant changes and is on the increase. Boulders have shown variation over the same period from 1965 to 1979. At Poverty Reach sand has decreased significantly since 1972 and while gravel, rubble and boulders have changed, the change is not statistically significant. Sand is being transported away from Poverty Reach leaving heavier particles of gravel, rubble and boulders.

3.5.2 Statistical analysis of ground data versus airphoto data

The second part of the analysis consisted of the comparison between the ground data and air photo data (Table 14). There being no ground data available for 1965, the air photo data for 1965 was dropped from the comparison. The approach offered a direct and readable comparison between two different techniques.

Table 11. Comparison between ground and air photo data, means and standard deviations of 10 transects of Boise data.

Site	Sediment	Ground Data		Air Photo Data		Remarks
		Means	S.D.	Means	S.D.	
Poverty Reach	S	16.4	15.9	19.8	11.7	Data of years
	G	58.0	23.9	57.5	15.5	1972, 1976,
	R	24.2	26.6	20.1	19.3	1979
	B	1.4	1.9	2.7	4.5	
Krassel Hole	S	11.6	8.7	42.2	8.6	Data of years
Reach	G	66.8	16.4	43.0	10.3	1972, 1976,
	R	16.7	14.3	10.4	3.7	1979
	B	4.9	3.3	4.6	3.9	

Table 12. Analysis of variance for Krassel Hole transects from airphoto data, 1965 to 1979 (modified design).

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	3	59.317	195.023*	35.272	50.475**
transects	9	107.331	224.909**	25.492	22.739**
error	27	52.430	52.650	16.050	6.360
total	39				
R^2		.450	.650	.440	.670

* P < .05; ** P < .01

Gravel and boulder compositions varied significantly from 1965 to 1979. All three sites differed significantly from one another in mean gravel and boulder distributions.

Table 13. Analysis of variance for Poverty reach transects from airphoto data, 1965 to 1979 (modified design).

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	3	339.906**	306.756	188.106	15.442
transects	9	469.43**	431.376*	1135.367**	52.211
error	27	53.27	128.950	78.530	10.690
total	39				
R^2		.780	.580	.840	.640

* P < .05; ** P < .01

Sand composition varied significantly from 1965 to 1979. All three sites differed significantly from one another in mean sand, gravel, rubble, and boulder distributions.

Table 14. Comparison of means and standard deviations (in %) (modified model).

	Ground Data		Air Photo Data	
	Means	Standard Deviation	Means	Standard Deviation
Poverty Reach (1972, 1976, 1979)				
Sand	16.4	15.9	19.8	11.7
Gravel	58.0	23.9	57.5	15.5
Rubble	24.2	26.6	20.1	19.3
Boulders	1.4	1.9	2.7	4.5
Krassel Reach (1972, 1976, 1979)				
Sand	11.6	8.7	42.2	8.6
Gravel	66.8	16.4	43.0	10.3
Rubble	16.7	14.3	10.4	3.7
Boulders	4.9	3.3	4.6	3.9

3.5.3 Test of normality

The statistical testing and analysis of variance procedures used in this study have been based on the assumption that the sampled airphoto interpreted data have been selected from a normal population. The normality test was made using Procedure Univariate of SAS. This procedure produces a test statistic for the null hypothesis that input data values are a random sample from a normal distribution. The data are tested against a normal distribution with mean and variance equal to the sample mean and variance. It was noticed that sand, gravel and rubble were normally distributed. Boulder indicated minus skewness, but several data values were zeros and no transformation was considered necessary in this case.

The ground data (Table 15) showed a significant decrease in sand and relative stability in gravel at Krassel Hole. The air photo data (Table 16) showed sand as stable but gravel on the increase. In the case of the Poverty ground data (Table 17) and air photo data (Table 18), both showed significant decreases in sand but relative stability in gravel and other two sediments.

The sand at Krassel Hole according to the air photo data from 1965-1979 was undergoing gradual changes but was not found statistically significant. From 1965 to 1972 all 10 transects were found to have heavy amounts of sand. From 1972 to 1979, the variation of the sand component among the 10 transects increased and was detected in the analysis of variance.

3.6 Interpretation of Computer Produced Maps

The interpretation of the computer-aided designed maps was made on an individual map basis. Krassel Hole reach map with sand distribution of 1965 was taken up first and examined for heavy and low concentrations of sand in the reach. The sand distribution pattern was studied on maps of years 1965, 1972, 1976 and 1979. The flow of the heavy sand deposits from 1965 to latter years was noted and the trend recorded. The gravel, rubble and boulder sediment maps were interpreted for the heavy concentrations and their flow patterns in the reaches over time. The heavy and low percent compositions of a particular sediment were related to other sediments. The interdependence of sand and gravel was particularly noted. The interpretation of Poverty reach maps was taken up after Krassel Hole reach computer maps.

The same sequence of interpretation was done on computer maps showing ground data sediments, once again starting with sand distribution

Table 15. Analysis of variance for ground data 1972, 1976 and 1979 Krassel Hole transects.

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	2	623.233**	409.733	422.933	1.433
transects	9	26.818	463.115*	301.837	20.459*
error	18	40.190	157.880	132.410	7.470
total	29				
R^2		.670	.640	.600	.580

* P < .05; ** P < .01

Sand changed significantly in composition from 1972 to 1979. All ten transects differed significantly from one another in mean gravel and boulder distributions.

Table 16. Analysis of variance for airphoto data, 1972, 1976, and 1979, Krassel Hole transects.

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	2	38.558	270.025**	46.075*	44.175*
transects	9	149.189**	215.111**	10.337	20.519*
error	18	39.750	33.970	12.190	8.700
total	29				
R^2		.660	.800	.460	.640

* P < .05; ** P < .01

Gravel decreased significantly in composition from 1972 to 1979. Rubble and boulder also changed during the same period. All ten transects differed significantly from one another in mean sand, gravel, and boulder distributions.

Table 17. Analysis of variance for ground data, 1972, 1976, and 1979, Poverty transects.

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	2	481.900**	589.633	12.900	0.633
transects	9	606.578**	1303.367**	2014.533**	6.996
error	18	51.790	203.410	132.230	2.370
total	29				
R^2		.870	.780	.880	.600

* P < .05; ** P < .01

Sand composition decreased significantly from 1972 to 1979. All ten transects differed significantly from one another in mean sand, gravel, rubble, and boulder distributions.

Table 18. Analysis of variance for airphoto data, 1972, 1976, and 1979, Poverty transects.

Source of variation	d.f.	Mean Squares			
		Sand	Gravel	Rubble	Boulder
years	2	379.453**	104.844	141.342	13.636
transects	9	304.153**	569.416**	980.519**	42.934**
error	18	24.750	90.520	92.080	9.240
total	29				
R^2		.890	.770	.850	.710

* P < .05; ** P < .01

Sand composition decreased significantly from 1972 to 1979. All ten transects differed significantly from one another in mean sand, gravel, rubble, and boulder distributions.

of 1965. The first set consisted of Poverty reach maps from airphoto data sediments. There were 16 individual maps, four for each sediment pertaining to four time periods, 1965, 1972, 1976 and 1979. This was followed by maps based on ground data.

The interpretation of airphoto data maps was followed by computer maps of Poverty reach produced from ground data for 1972, 1976 and 1979. These were compared visually and by overlaying maps over airphoto data maps. Agreement and discrepancies were discussed and explained. The attention was mainly focused on heavy concentration of the sediment and its flow in the channel over time as discussed above.

3.6.1 Krassel Hole reach computer maps with airphoto data

3.6.1.1 Krassel Hole reach map with sand distribution

Four computer maps were produced using sand data from airphotos. The investigation of the maps, Figure 30, showed that in 1965, a heavy concentration of sand existed in columns from 110 to 130, in the straight portion of the river channel and in columns from 50 to 70, which is the steep part of the meander. In 1972, the previous heaviest concentration was reduced from 51 percent to 28 percent on the straight line portion and shifted downward with an increase from 34 percent to 35 percent. The meander concentration shifted from the existing location to a new position in the meander, thus raising the existing 34 percent concentration to 49 percent.

In 1976, sand occupied a larger area in the meander with 52 percent composition but with a reduced composition from 28 to 46 percent in the remaining part of the reach. The increased percent in sand composition can be attributed to a heavier than average precipitation in this watershed during 1975-76.

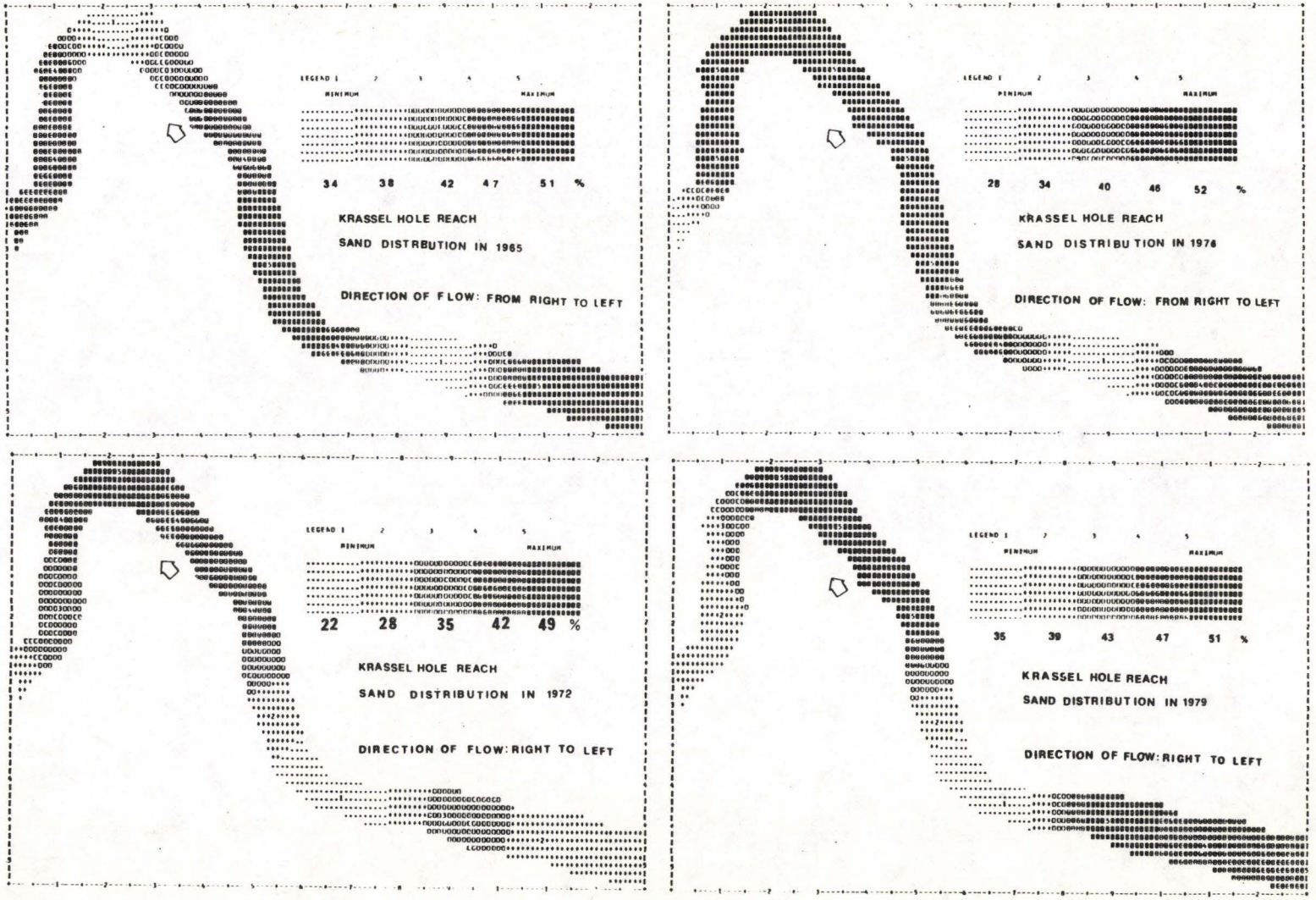


Figure 30. Computer produced time trend map of Krassel Hole reach showing sand composition from 1965 to 1979, based on airphoto data.

In 1979, the greater portion of 52 percent sand composition was reduced to the 43-51 percent range and sand in the steep portion (columns 1-15), was changed from a range of 28-46 percent to 39-43 percent. In columns 80 to 95, the percent increased from 28 percent to 47-51 percent.

The channel has been going through a recovery and clearing itself of a heavy sand deposition by disposing of the finer sand particles.

3.6.1.2 Krassel Hole reach map with gravel distribution

Gravel had 59 percent composition in the middle of the straight line portion of the channel and the minimum, i.e., the average 30 percent concentration in the meander portion in 1965, as shown in Figure 31.

The concentration increased from an average of 37-44 percent range to a 59-65 percent in the straight portion. During the same period from 1965 to 1972, the corresponding composition of sand was reduced to 28-35 percent range. This showed a mutual but significant reciprocity between sand and gravel.

The gravel composition in 1976 remained low at 21 percent in the meander portion and increased to 36-44 percent in 1979. Between 1965 and 1979 the rise in gravel percent increased from 30 percent to 36-44 percent in the meander portion and from an average of 44 to 46 percent. There was an overall change in gravel distribution from a minimum of 36 percent to a maximum of 47 percent. The increase was reciprocated by a corresponding decrease in sand percent in the straight line portion as well as in the steep portion of the channel in this reach.

3.6.1.3 Krassel Hole reach map with rubble distribution

There was no significant change in the rubble distribution. The percent range varied from 4-20 percent in 1975 (Figure 32) to a 6-10 percent in 1979.

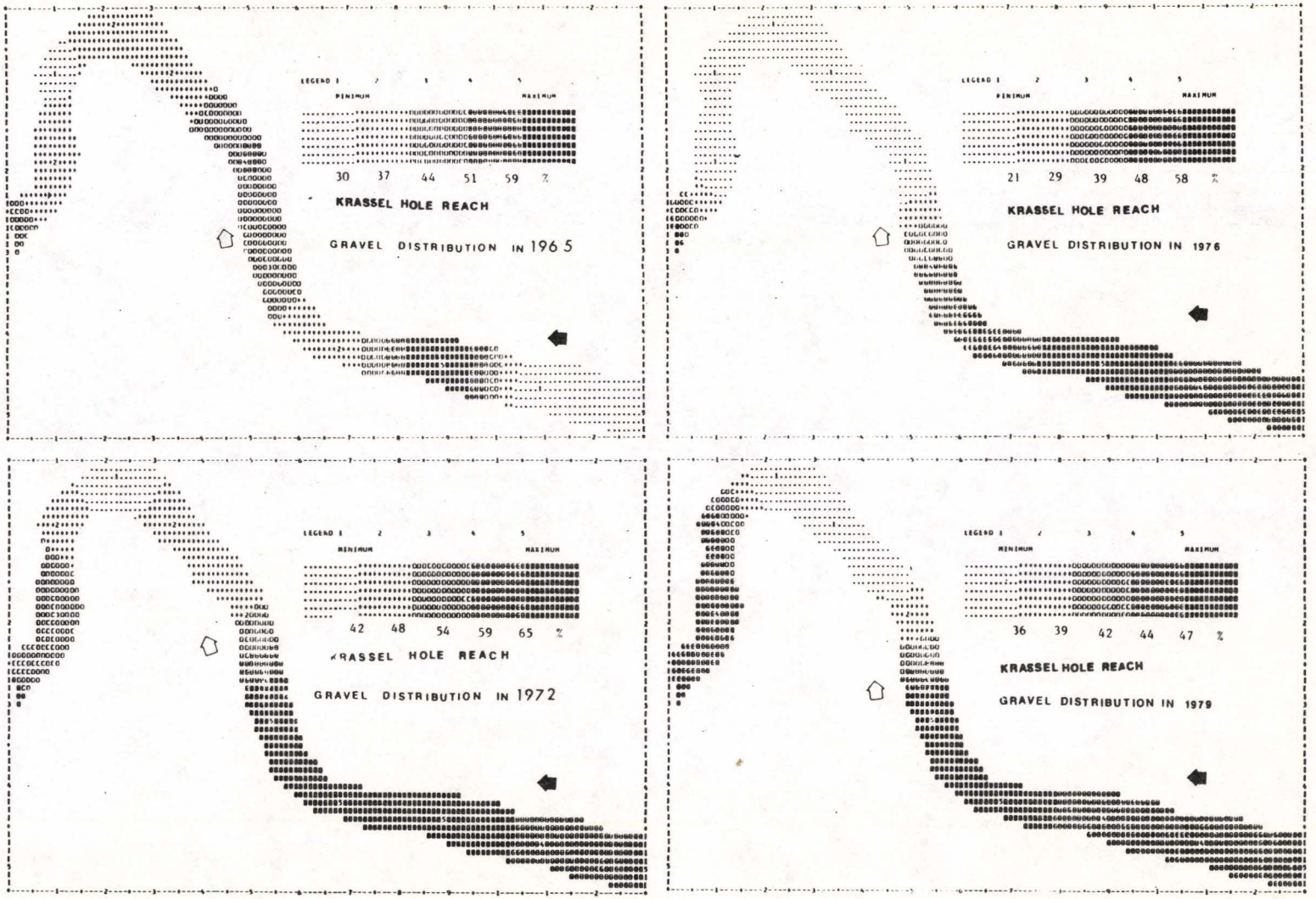

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
30 37 44 51 59 %
KRASSEL HOLE REACH
GRAVEL DISTRIBUTION IN 1965
21 29 39 48 58 %
KRASSEL HOLE REACH
GRAVEL DISTRIBUTION IN 1976
42 48 54 59 65 %
KRASSEL HOLE REACH
GRAVEL DISTRIBUTION IN 1972
36 39 42 44 47 %
KRASSEL HOLE REACH
GRAVEL DISTRIBUTION IN 1979

Figure 31. Computer produced time trend map of Krassel Hole reach showing gravel composition from 1965 to 1979, based on airphoto data.

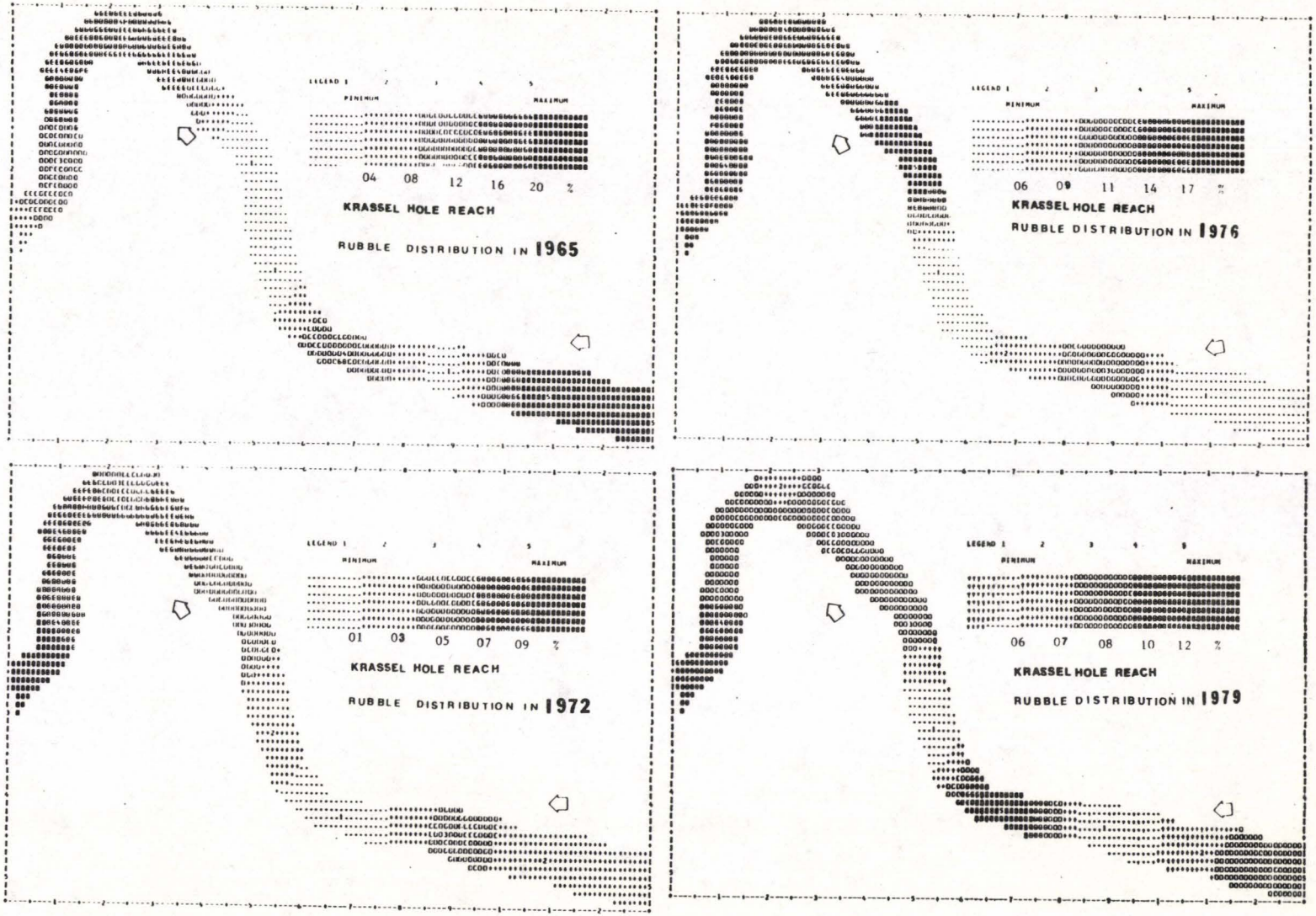

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
04 08 12 16 20 %
KRASSEL HOLE REACH
RUBBLE DISTRIBUTION IN 1965
06 09 11 14 17 %
KRASSEL HOLE REACH
RUBBLE DISTRIBUTION IN 1976
01 03 05 07 09 %
KRASSEL HOLE REACH
RUBBLE DISTRIBUTION IN 1972
06 07 08 10 12 %
KRASSEL HOLE REACH
RUBBLE DISTRIBUTION IN 1979

Figure 32. Computer produced time trend map of Krassel Hole reach showing rubble composition from 1965 to 1979, based on airphoto data.

3.6.1.4 Krassel Hole reach map with boulder distribution

The boulder composition varied from an average 3 percent (Figure 33) in 1965, to an average of 5 percent, which is considered insignificant.

The heavier sediments of rubble and boulder were stable during the period from 1965 to 1979.

3.6.2 Krassel Hole reach computer maps with ground data

3.6.2.1 Krassel Hole reach computer map with sand distribution

Ground data of 1972, 1976, and 1979 were used for computer mapping since data for 1965 was not available. Columns 110 to 130, Figure 34, depicted 35 percent as the highest concentration of sand. The next 20 columns, 90-110 showed a decrease in percent from 29 to 24. The same trend continued with the minimum sand percent around column 70. A similar trend was noticed between columns 70 and 110 on computer map using airphoto data.

Columns 45 to 65 showed a drop in sand composition on the ground data map, with an upward trend from column 45 to 1. The airphoto data map showed a steep rising trend up to column 15 and then a trend similar to the ground data computer map.

The 1976 computer map showed 17 percent as the highest sand percent in columns from 80 to 95 with a decrease in percent right back to column 50 where it is just 6 percent. In contrast, the airphoto map showed 46 percent of sand in the same region. This extreme divergence between the two maps is in conformity with the statistical analysis results and are discussed there.

The ground crew determined that the coarse material appearing on the sediment bar in the riverbed as gravel, whereas airphoto interpreters

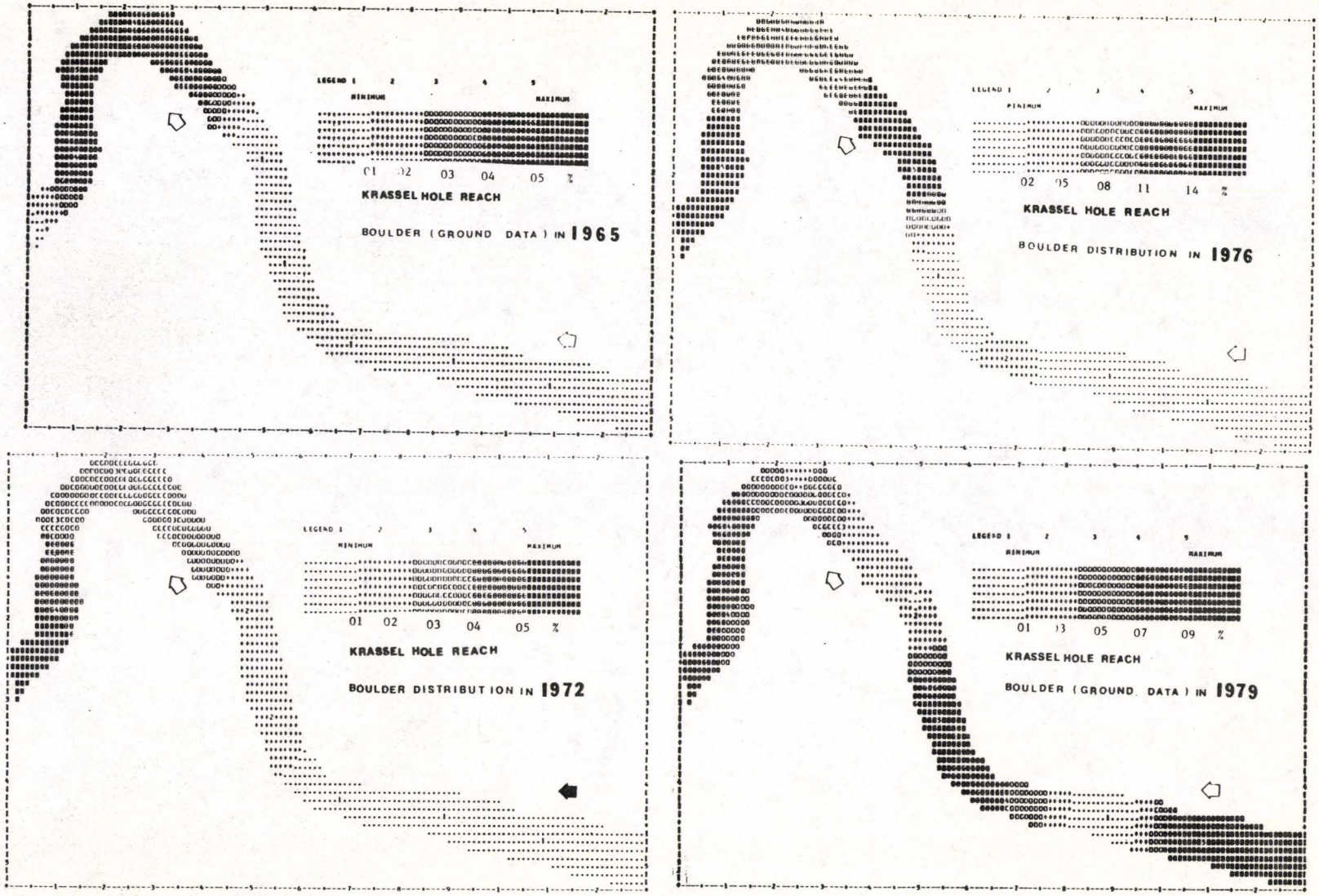

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
01 02 03 04 05 %
KRASSEL HOLE REACH
BOULDER (GROUND DATA) IN 1965
02 05 08 11 14 %
KRASSEL HOLE REACH
BOULDER DISTRIBUTION IN 1976
01 02 03 04 05 %
KRASSEL HOLE REACH
BOULDER DISTRIBUTION IN 1972
01 03 05 07 09 %
KRASSEL HOLE REACH
BOULDER (GROUND DATA) IN 1979

Figure 33. Computer produced time trend map of Krassel Hole reach showing boulder composition from 1965 to 1979, based on airphoto data.

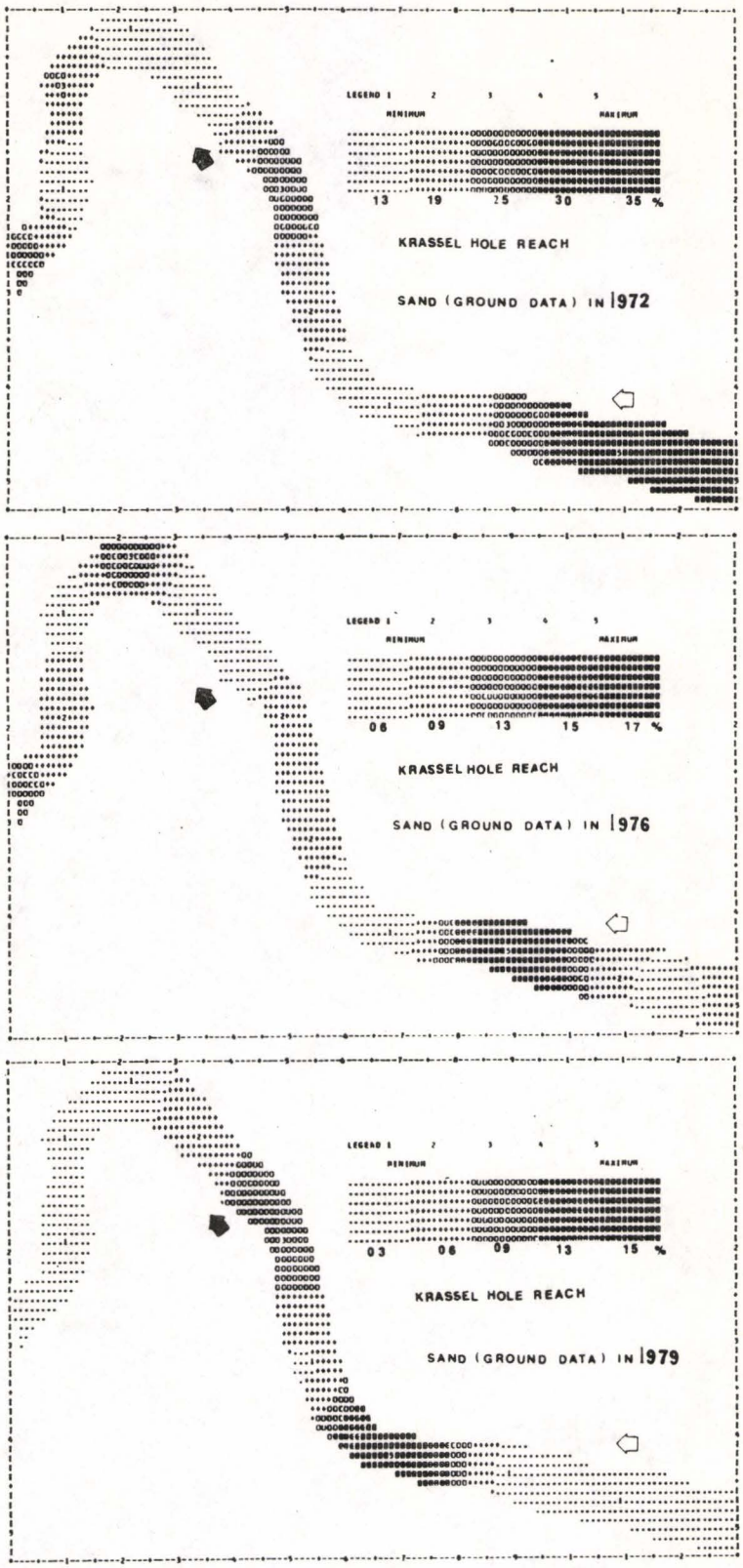


Figure 34. Computer produced time trend map of Krassel Hole reach showing sand composition from 1972 to 1979, based on ground data.

classified it as sand. This discrepancy in classification affected the results for both sand and gravel with the effect that a maximum contrast was noticeable in sand distribution at this reach on airphotos.

In 1979, sand had a maximum concentration between columns 60 and 75 and then dropped to a lower percent extending right up to column 50. The declining trend is in agreement with the airphoto data computer map. There is a rise in sand percent from column 45 to 35 and thereafter the trend shows a drop in sand percent. The trends are similar to those on the airphoto data map. However, the airphoto map shows more sensitivity and subtle variations in the time trends.

3.6.2.2 Krassel Hole reach computer map with gravel distribution

The highest concentration of gravel is distributed over most of the reach in the 1972 computer map, Figure 35. Columns 1 to 85 displayed the gravel percent from 55 to 77 with a decreasing percent in columns 85 to 130, which have only 33-44 percent of gravel.

The airphoto data computer map showed 42-65 percent of gravel in columns 1 to 100. The percent declines to 59 in columns 95 to 130. The composition showed only minor variations.

The gravel percentage in 1976 was found heaviest in columns 55 to 80 and then started decreasing to either side. It reached the highest percent in columns 40 to 45 and started decreasing from column 30 to 1. The airphoto data map showed a decreasing trend with no peak levels.

In 1979, the highest percent of gravel was in columns 40-55 and decreased on either side while the minimum of 56 percent occurred in columns 100 to 130. The meander portion shows gravel varying from 72 to 80 percent.

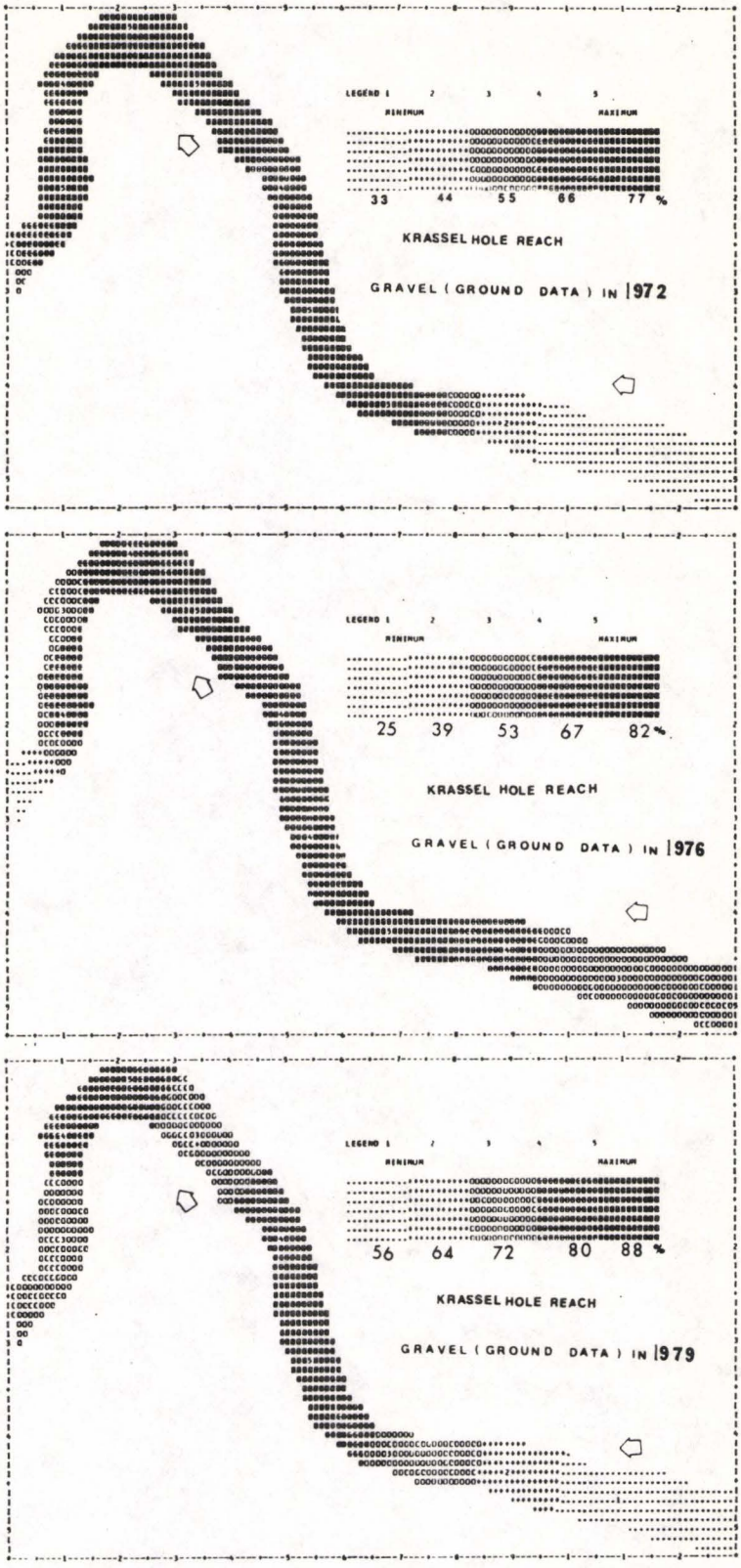

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
33 44 55 66 77 %
KRASSEL HOLE REACH
GRAVEL (GROUND DATA) IN 1972
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
25 39 53 67 82 %
KRASSEL HOLE REACH
GRAVEL (GROUND DATA) IN 1976
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
56 64 72 80 88 %
KRASSEL HOLE REACH
GRAVEL (GROUND DATA) IN 1979

Figure 35. Computer produced time trend map of Krassel Hole reach showing gravel composition from 1972 to 1979, based on ground data.

The airphoto computer map showed decreased gravel percent on either side of columns 45 to 75. The minimum occurred in the meander part in columns 15-50 with 36 percent while columns 100 to 130 showed 44 percent which is a decrease of over 10 percent.

The difference is conspicuous in the meander and is analogous to the one in sand distribution. Since gravel was inflated in the ground estimates, this bias resulted in a higher percent of gravel than the airphoto computer map which was biased in favor of sand.

3.6.2.3 Krassel Hole reach map with rubble distribution

Rubble was stable in all the four maps from 1972 to 1979 (Figure 36). The time trend is in close agreement with the airphoto data. The lower percent composition occurred in the left half of the reach and rose toward the right edge, with the heaviest concentration sited in the columns 100 to 130. The agreement between the airphoto data map and the ground data map was conspicuous in this case.

3.6.2.4 Krassel Hole reach map with boulder distribution

Boulder distribution was stable from 1965 to 1979 as shown in all the four maps. The same trends are seen in the airphoto data maps. The maximum agreement is in the boulder computer maps (Figure 37).

3.6.3 Poverty reach computer produced maps using airphoto data

3.6.3.1 Poverty reach computer map with sand distribution

Four maps for 1965, 1972, 1976, and 1979 using airphoto data were produced. In the 1965 map (Figure 38) the heaviest concentration of sand, 35-45 percent occurring in columns 1 to 50, was reduced to 25-32 percent in 1972.

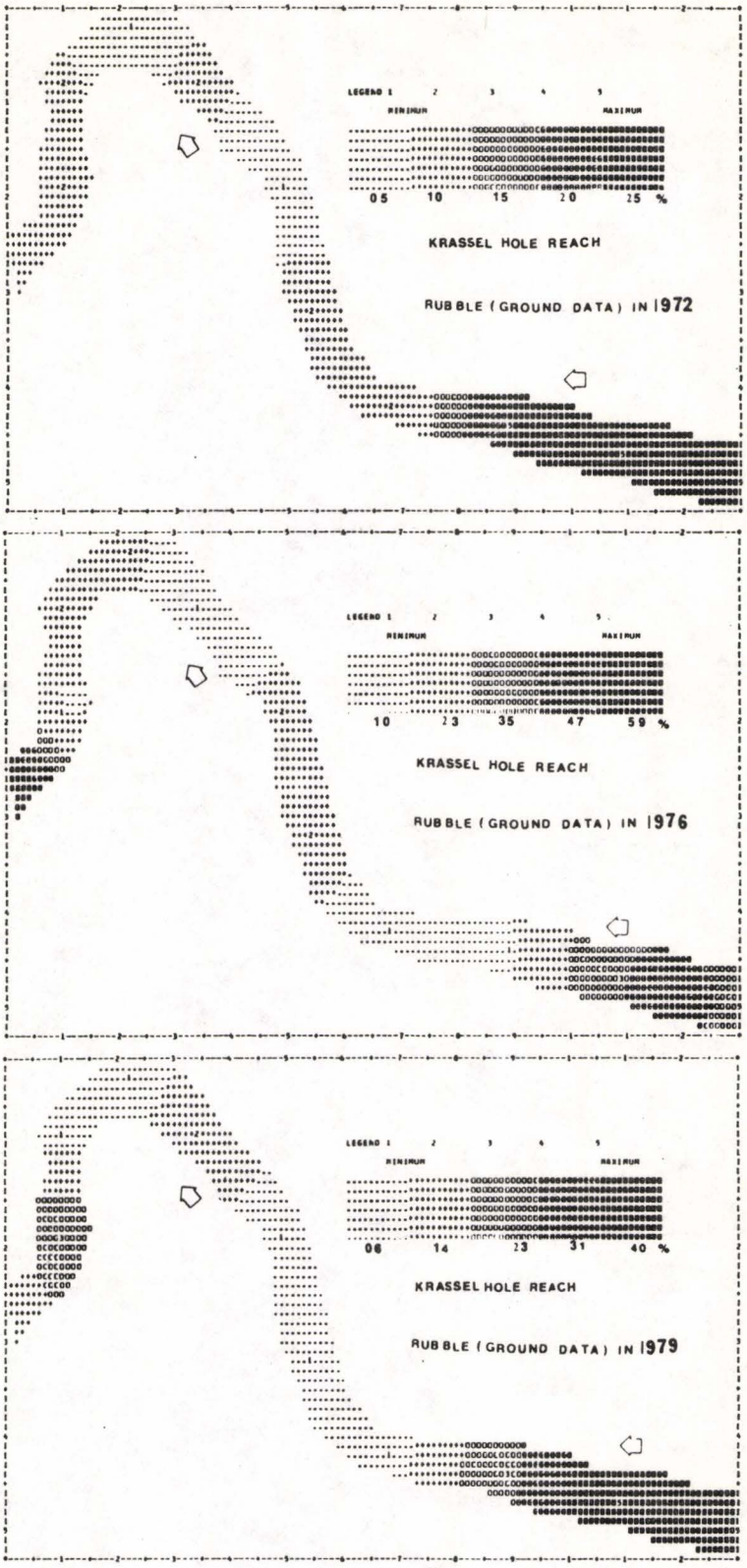


Figure 36. Computer produced time trend map of Krassel Hole reach showing rubble composition from 1972 to 1979, based on ground data.

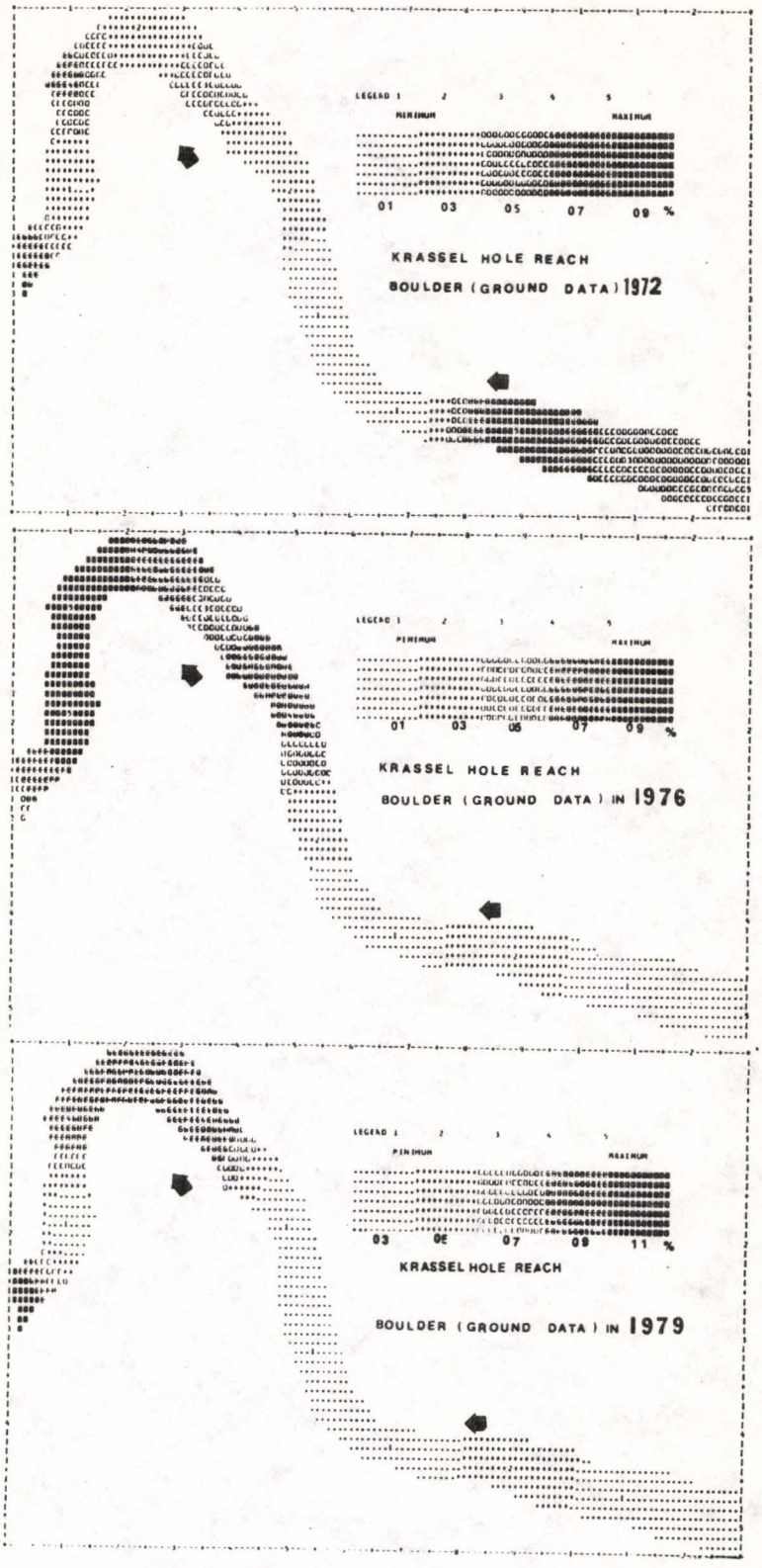


Figure 37. Computer produced time trend map of Krassel Hole reach showing boulder composition from 1972 to 1979, based on ground data.

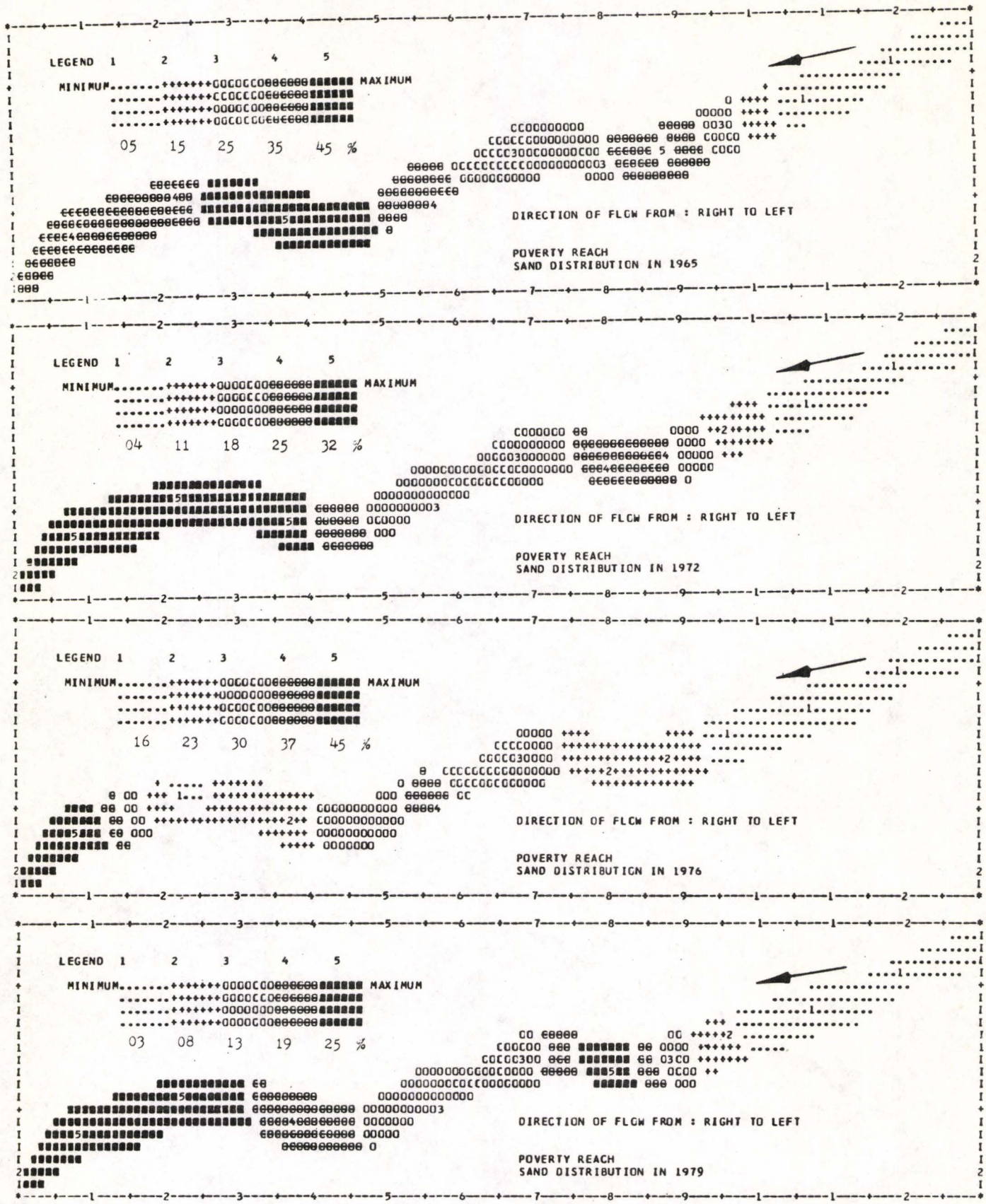

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
05 15 25 35 45 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
SAND DISTRIBUTION IN 1965
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
04 11 18 25 32 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
SAND DISTRIBUTION IN 1972
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
16 23 30 37 45 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
SAND DISTRIBUTION IN 1976
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
03 08 13 19 25 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
SAND DISTRIBUTION IN 1979

Figure 38. Computer produced time trend map of Poverty reach showing sand composition from 1965 to 1979, based on airphoto data.

In 1976 the previous heavy concentration of 45 percent shifted downstream to columns 1 to 15 and the stretch from columns 10 to 50 displayed an average of 23-37 percent composition of sand. In the same columns sand percent was 19-25 percent in 1979.

The composition of sand in columns 1-50 was 35-45 percent in 1965, 25-32 percent in 1972, 16-45 percent in 1976, and 19-25 percent in 1979. There was overall a mild drop in sand composition between 1965 and 1979. The minimum sand percent continued to be in the extreme right end of the reach from 1965 to 1979. The clearing of sand was slow but continuous.

3.6.3.2 Poverty reach computer map with gravel distribution

In 1965 the gravel composition in the stretch from columns 1 to 50 (Figure 39) ranged from 48-58 percent. In 1972 the range varied from 53-61 percent which was a moderate change. In 1976 the composition of gravel on the same stretch had increased from 48-71 percent and showed an increase to the right side of the reach length as well.

In 1979 the gravel composition had increased to an average of 61-73 percent compared to an average of 48-59 percent in 1965. This is over a 10 percent increase in this sediment. However, over the same period there was a drop in sand composition.

The finer particles of sand were transported and simultaneously uncovering the hidden, heavier and coarser particles of gravel in the river channel.

3.6.3.3 Poverty reach computer map with rubble distribution

The heavy concentration of rubble with a 40 percent composition was noticed in the rightmost edge (Figure 40) in columns from 115 to 130 during 1965. The minimum percent was found in the left half reach with

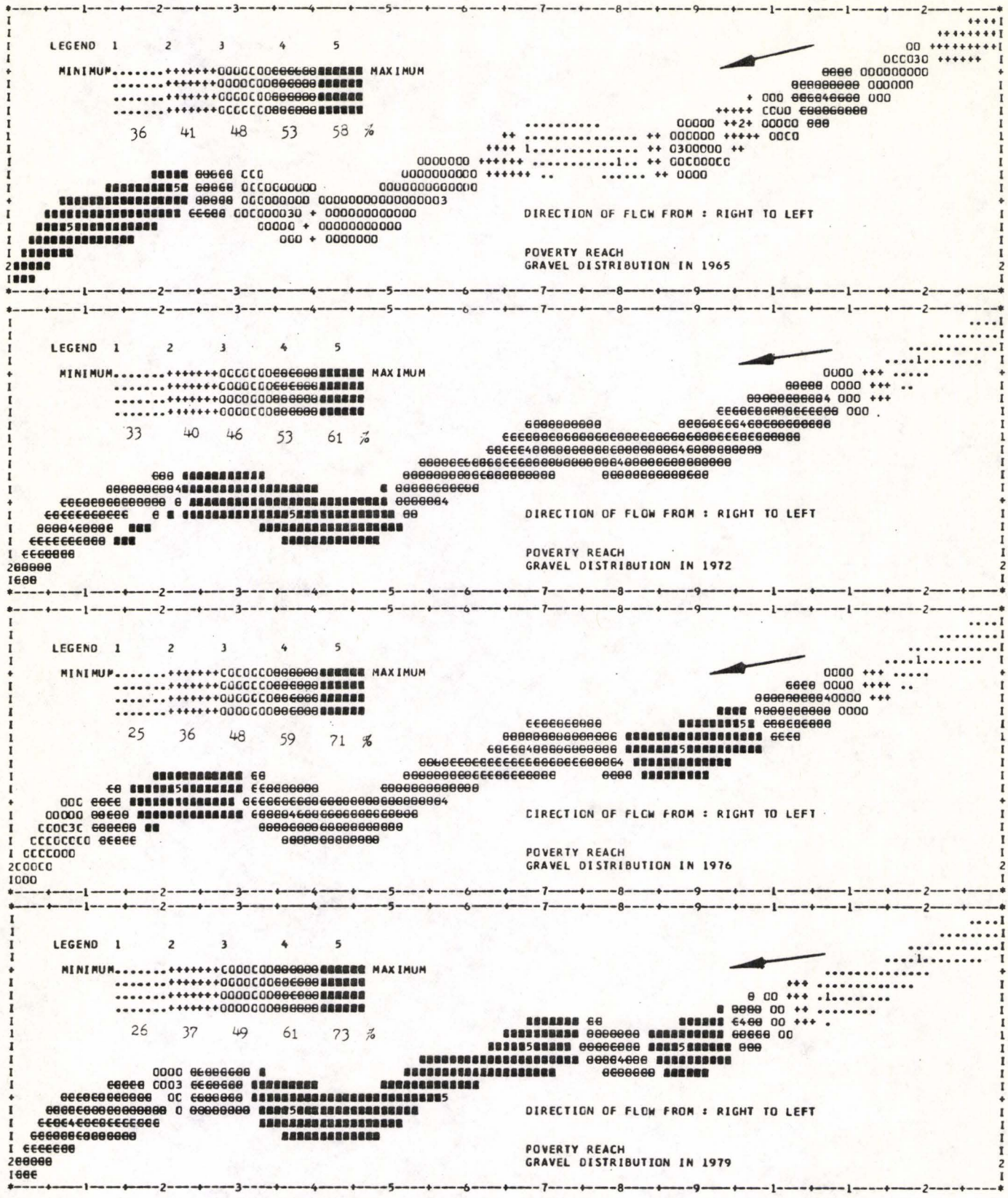

LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
36 41 48 53 58 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL DISTRIBUTION IN 1965
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
33 40 46 53 61 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL DISTRIBUTION IN 1972
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
25 36 48 59 71 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL DISTRIBUTION IN 1976
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
26 37 49 61 73 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL DISTRIBUTION IN 1979

Figure 39. Computer produced time trend map of Poverty reach showing gravel composition from 1965 to 1979, based on airphoto data.

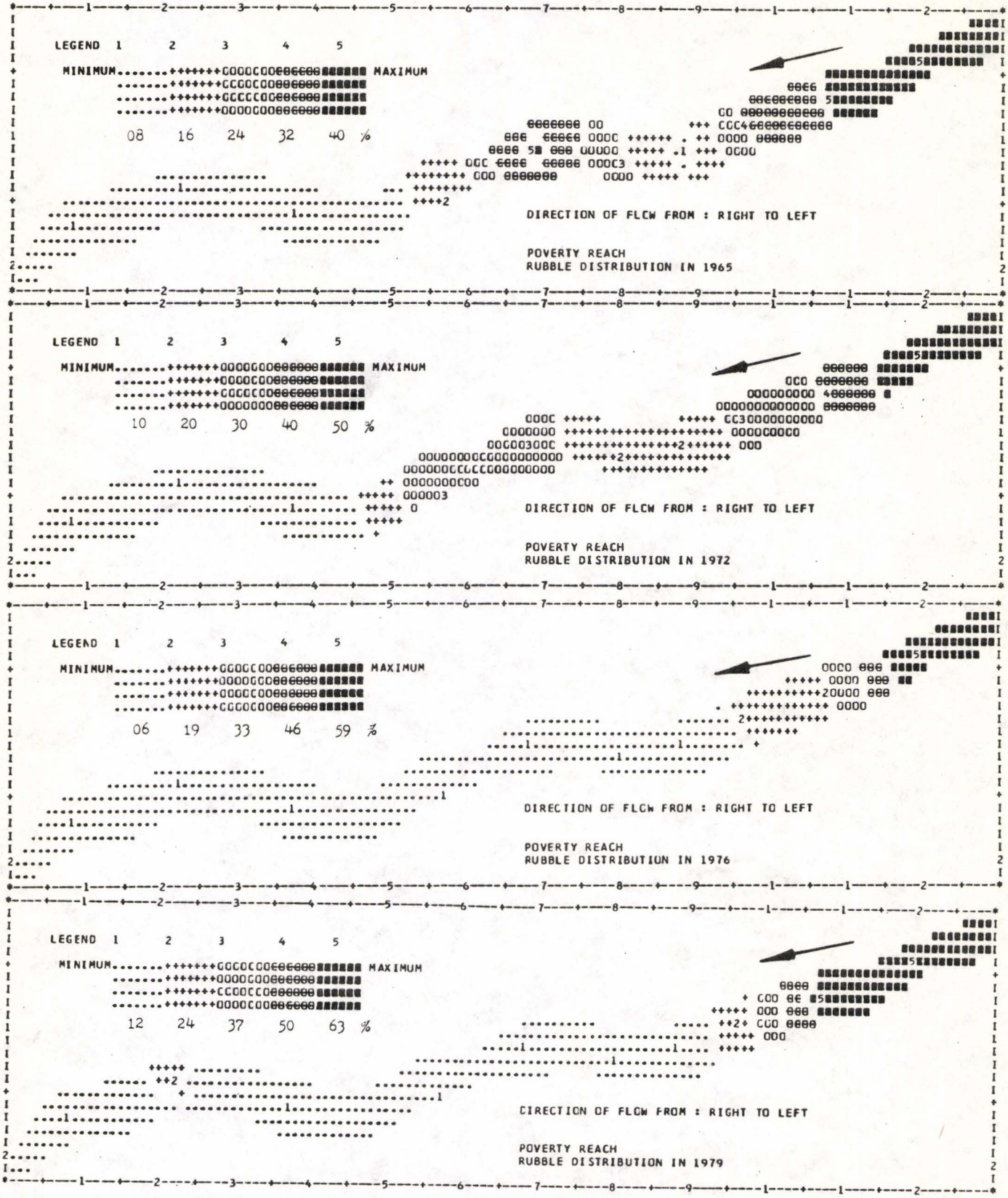

LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
08 16 24 32 40 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE DISTRIBUTION IN 1965
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
10 20 30 40 50 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE DISTRIBUTION IN 1972
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
06 19 33 46 59 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE DISTRIBUTION IN 1976
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
12 24 37 50 63 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE DISTRIBUTION IN 1979

Figure 40. Computer produced time trend map of Poverty reach showing rubble composition from 1965 to 1979, based on airphoto data.

an 8 percent composition. There was practically no change in the composition in this case until 1979. Rubble has been a stable bedded sediment in this reach.

3.6.3.4 Poverty reach computer map with boulder distribution

The boulder composition varied from 1-13 percent in 1965 and changed to 2-15 percent in 1979. Boulder displayed no variation (Figure 41) in its composition and has been stable during the period from 1965 to 1979.

3.6.4 Poverty reach computer maps from ground data

3.6.4.1 Poverty reach computer map with sand distribution

Sand distribution in 1972 had the highest percent in columns 1 to 25 (Figure 42) and decreased by stages right up to column 130.

The airphoto data map has exactly the same trend with highest percent in columns 1 to 40 and decrease in percent right up to column 130.

The 1976 map showed the highest sand percent in columns 1 to 20 and a gradually decreasing trend right up to columns 130.

The 1976 airphoto map had the highest sand percent in columns 1 to 15 and decreasing percent up to column 40. A slight rise continues up to column 60 with a gradual decrease thereafter until column 130. The airphoto interpreted map shows more variations in sediments because it is a continuous inventory technique compared to ground data which is a selective sampling technique.

The 1979 map showed the highest sand percent between columns 15 and 25 and a decrease on either side with 5-14 percent. The minimum, 5 percent, occurred between columns 95 and 130.

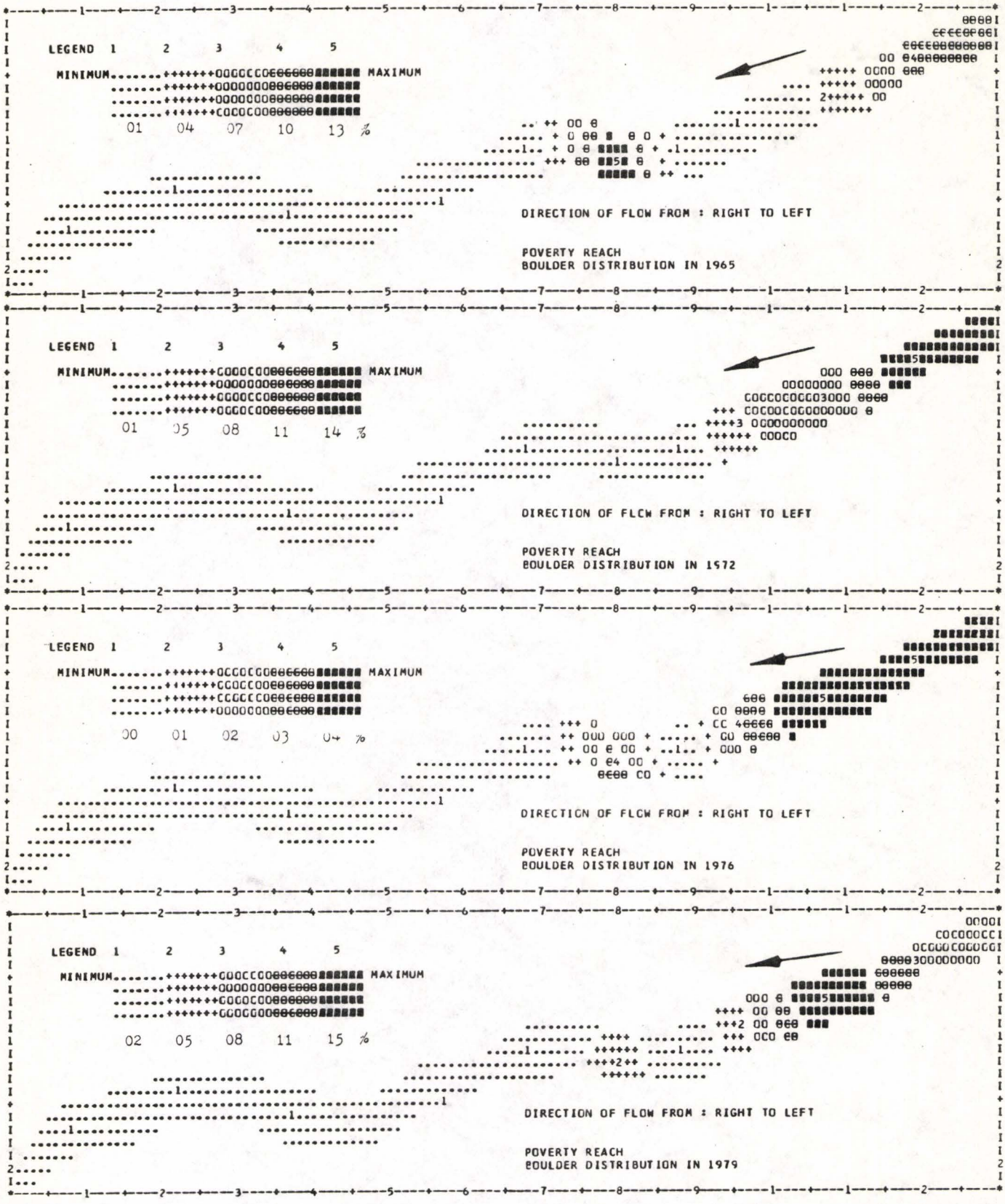

LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
01 04 07 10 13 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER DISTRIBUTION IN 1965
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
01 05 08 11 14 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER DISTRIBUTION IN 1972
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
00 01 02 03 04 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER DISTRIBUTION IN 1976
LEGEND 1 2 3 4 5
MINIMUM MAXIMUM
02 05 08 11 15 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER DISTRIBUTION IN 1979

Figure 41. Computer produced time trend map of Poverty reach showing boulder composition from 1965 to 1979, based on airphoto data.

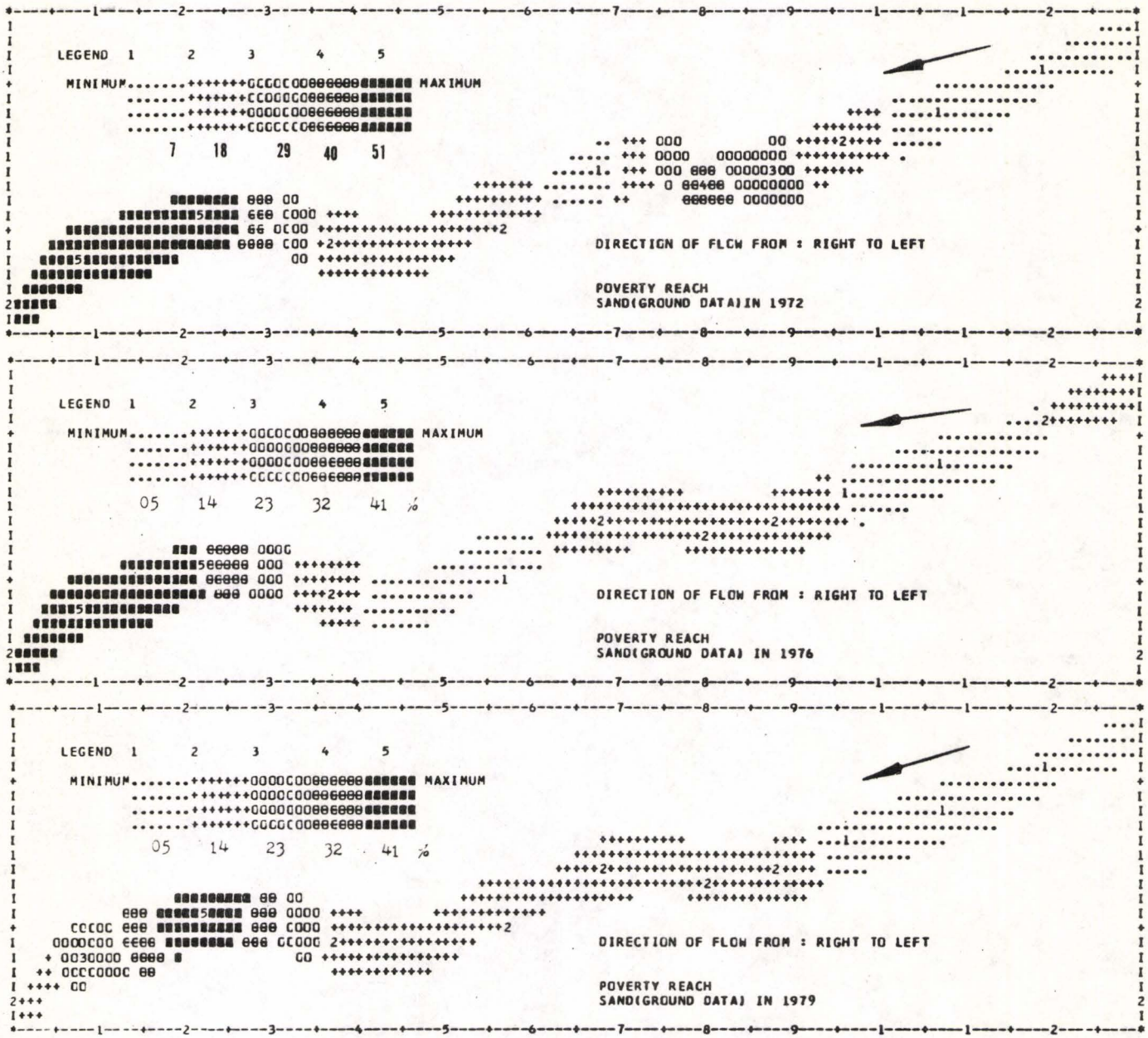


Figure 42. Computer produced time trend map of Poverty reach showing sand composition from 1972 to 1979, based on ground data.

The airphoto data map showed highest percent between column 1 and 30 and thereafter decrease up to column 70 and a rise up to column 85 which was followed by a stepwise decrease right up to column 130. The minimum, 3 percent, occurred between columns 95 to 130.

3.6.4.2 Poverty reach computer map with gravel distribution

In 1972 a heavy gravel concentration with a composition of 67 percent was located between columns 35 and 45 and from 90 to 100. The percent of gravel composition gradually decreased in column 100 to 130 to a minimum of 33 percent (Figure 43).

The concentration increased to 78 percent in 1976 and was spread over columns 30 to 90. There was a gradual decrease on either side of these columns reaching a minimum of 16 percent in columns 100 to 130.

In 1979 the gravel composition percent increased to 85 percent in columns 30 to 90. The percent varied from 55 to 85 percent in columns 1 to 30 as compared to 33 and 51 percent in 1965, thereby showing an increase of 20 to 30 percent in these columns of the reach. The minimum percent of composition continued to be in columns 100 to 130, the portion of the reach that has been dominated by rubble and boulder.

The computer map produced from airphoto data agreed with high and low gravel concentrations and indicated similar trends of gradually decreasing percent towards column 130, the extreme right tip of the reach.

3.6.4.3 Poverty reach computer map with rubble distribution

The 1972 computer map of rubble ground data (Figure 44) is similar to the airphoto data map. The same is true for 1976 and 1979. There is no significant variation in the rubble distribution over time. The trends are in agreement with the airphoto data maps.

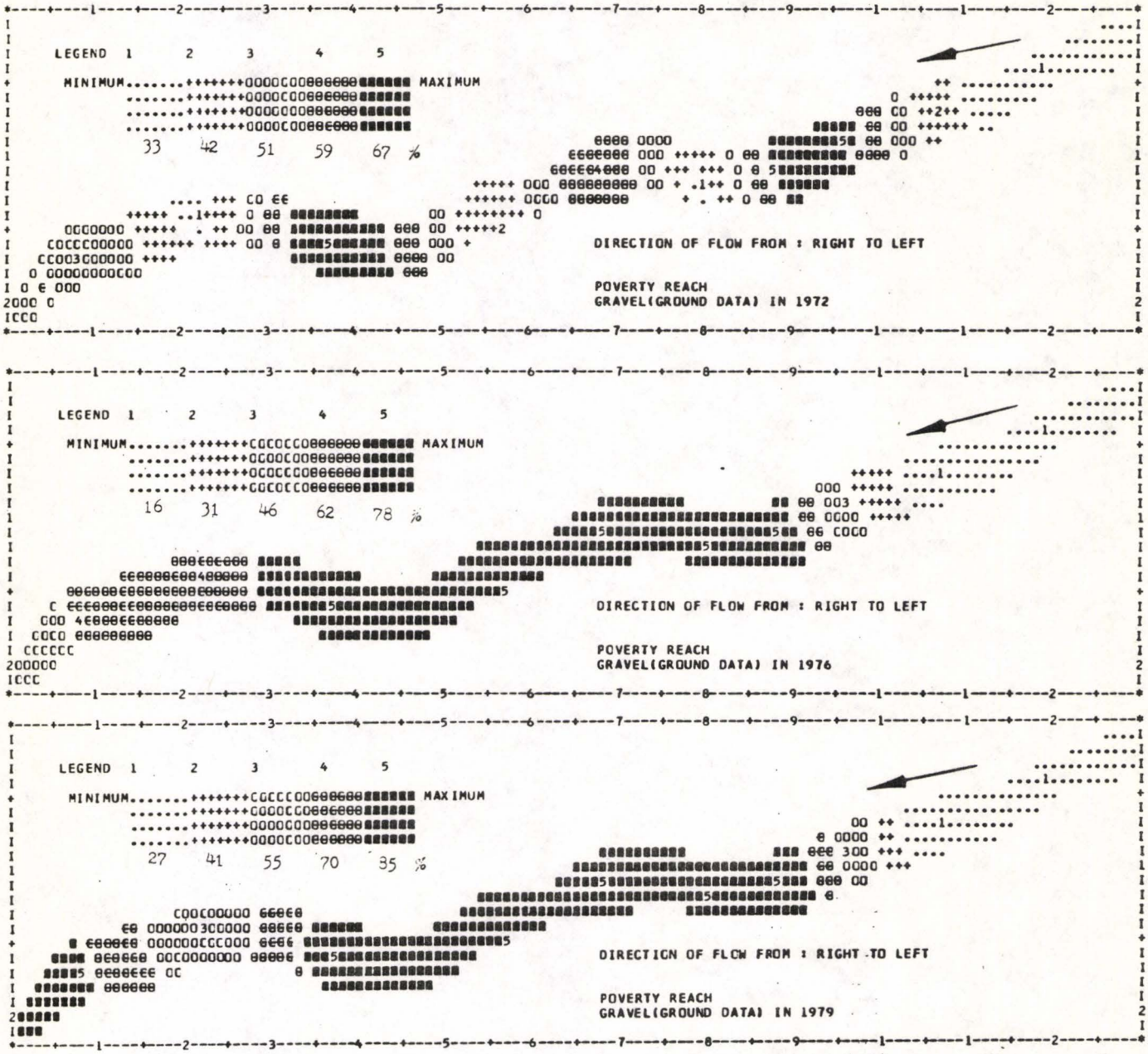

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
33 42 51 59 67 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL(GROUND DATA) IN 1972
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
16 31 46 62 78 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL(GROUND DATA) IN 1976
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
27 41 55 70 85 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
GRAVEL(GROUND DATA) IN 1979

Figure 43. Computer produced time trend map of Poverty reach showing gravel composition from 1972 to 1979, based on ground data.

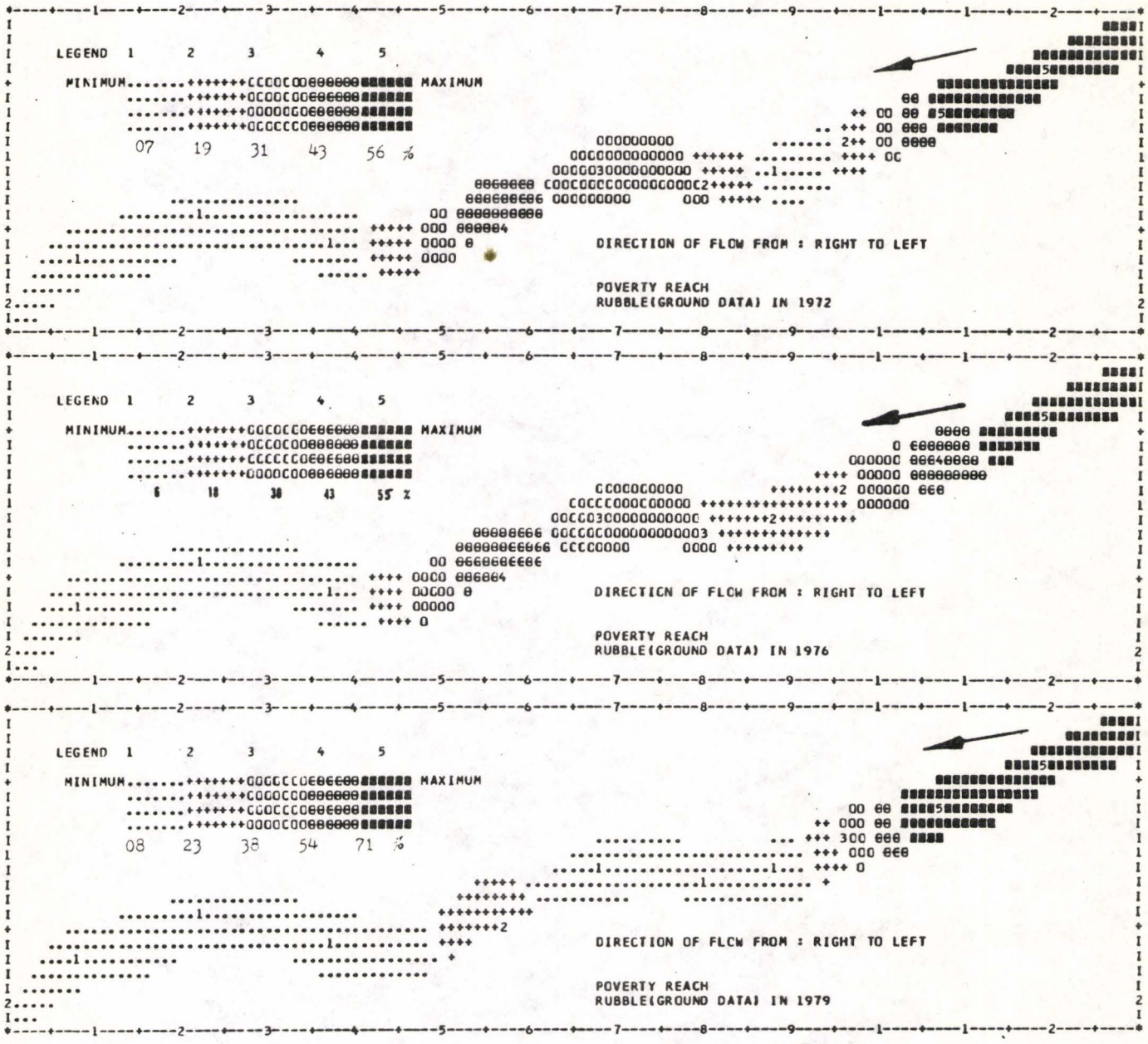

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
07 19 31 43 56 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE(GROUND DATA) IN 1972
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
6 18 30 43 55 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE(GROUND DATA) IN 1976
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
08 23 38 54 71 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
RUBBLE(GROUND DATA) IN 1979

Figure 44. Computer produced time trend map of Poverty reach showing rubble composition from 1972 to 1979, based on ground data.

3.6.4.4 Poverty reach computer map with boulder distribution

All the four computer maps, Figure 45, were found in close agreement, each one showing the highest boulder concentration extending from column 115 to 130 and a gradual decrease from column 115 to column 1, with variation in the composition from 0 to 10 percent.

3.7 Comparison between large scale and small scale airphotos

The planimetric maps (Appendix Figures 1-5) prepared from large scale airphotos and small scale airphotos were compared for the overlapping periods of 1965 and 1972. All five sediment types, sand, gravel, cobble, rubble and boulder, were included in the interpretation. The area in square meters and percent was computed for each sediment and statistically analyzed.

Table 19 shows the comparison between large and small scale airphoto interpretation of sediments for 1965 and 1972. The results obtained from the small scale airphotos compared fairly well with those of large scale airphotos even though the small scale photos were black and white and no sediment size could be measured at this scale. Detection of sediments is feasible on the small scale airphotos in broad categories of combined sand and gravel and rubble and boulders.

Table 19. Comparison between large scale and small scale sediments for 1965 and 1972.

Sediment	Mean		Standard Deviation		Standard Error	
	Large Scale	Small Scale	Large Scale	Small Scale	Large Scale	Small Scale
Sand	30.0	39.0	11.3	12.7	8.0	9.0
Gravel	37.5	33.0	6.3	1.4	4.5	1.0
Cobble	18.5	9.5	14.8	9.1	10.5	6.5
Rubble	10.0	9.0	2.8	2.8	2.0	2.0
Boulder	4.0	9.5	0.0	2.1	0.0	1.5

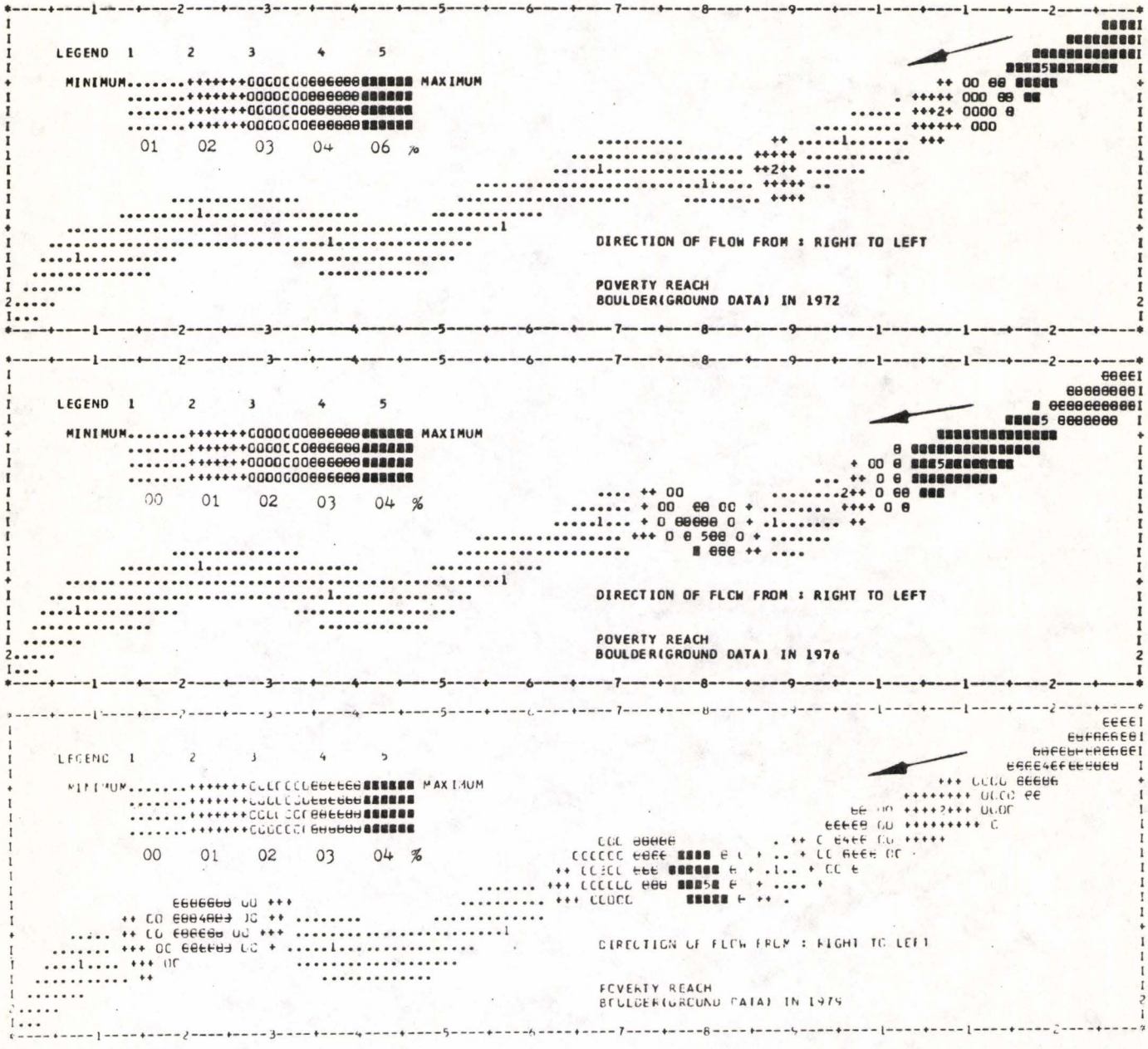

LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
01 02 03 04 06 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER(GROUND DATA) IN 1972
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
00 01 02 03 04 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER(GROUND DATA) IN 1976
LEGEND 1 2 3 4 5
MINIMUM
MAXIMUM
00 01 02 03 04 %
DIRECTION OF FLOW FROM : RIGHT TO LEFT
POVERTY REACH
BOULDER(GROUND DATA) IN 1979

Figure 45. Computer produced time trend map of Poverty reach showing boulder composition from 1972 to 1979, based on ground data.

3.8 Estimation of accuracy of the photo-interpreted information

The accuracy of photo-interpretation was computed for all the four sediments using Boise data and for the five sediments using McCall data (Table 20). The relative error for the four sediments was based on all observations of the three different years, 1972, 1976, and 1979 of the 10 transects for each year. The relative error was computed individually for Krassel Hole reach and Poverty reach and then for the combined data of the two reaches. This helped to identify the area of closer agreement between the ground and airphoto data.

The relative error for the three reaches, Krassel Hole, Poverty, and Oxbow was computed using data of eight cross-sections for the year 1979. The McCall ground data, as mentioned previously, was available for 1979 only. In this case cobble was the fifth sediment included in the computations of the relative error.

The accuracy of the photo-interpretation compares best with the McCall data 10 percent, next was the Poverty reach 11 percent, and lowest was obtained for Krassel Hole using Boise ground data.

The equations were set up as follows:

D = SQRT ((SAP-SGD)**2+(GAP-GGD)**2+(RAP-RGD)**2+(BAP-BGD)**2)

and

DMAX = SQRT ((100)**2+(100)**2+(100)**2+(100)**2)

Averr = (D/DMAX)*100 (percent)

where D = the error vector in the four-dimensional space of the four sediments.

DMAX = the maximum error vector that can have value equal to 100 for each of the four sediments.

DMAX = the maximum error vector that can have value equal to 100 for each of the four sediments.

SAP = sand from aerial photographs

SGD = sand from ground data, etc.

It is understood that D will include an additional term (CAP-CGD)**2, and DMAX would have (100)**2 when the fifth sediment cobble is added.

Table 20. The accuracy of interpreted airphoto data computed with respect to Boise ground data and McCall ground data separately.

Source of variations	df	Mean square	Average error (percent)	Data used
Sand	1	19.45 Model	11	10 transects at
Gravel	1	44.17 Error		Poverty reach vs.
Rubble	1			Boise data
Boulder	1			
Error	25			
Total	29			
Sand	1	137.67 Model	23	10 transects at
Gravel	1	33.56 Error		Krassel Hole reach
Rubble	1			vs. Boise data
Boulder	1			
Error	25			
Total	29			
Sand	1	283.86 Model	17	Poverty and
Gravel	1	62.96 Error		Krassel Hole reaches
Rubble	1			combined 20 transects
Boulder	1			vs. Boise data
Error	55			
Total	59			
Sand	1	27.20 Model	10	Three reaches:
Gravel	1	2.08 Error		Krassel Hole reach,
Cobble	1			Poverty reach,
Rubble	1			and Oxbow reach
Boulder	1			vs. McCall data
Error	2			
Total	7			

The two sets of observations made under the modified design were tested using Duncan's Least Significant Difference procedure and their difference was found statistically insignificant.

Based on the combined 1979 aerial photo transect data of Krassel Hole and Poverty reach, this study established that the channel in those reaches of the South Fork of the Salmon River has 27 percent sand, 53 percent gravel, 17 percent rubble and 3 percent boulders. The comparative figures from the Boise ground data are 8 percent sand, 65 percent gravel, 22 percent rubble, and 3 percent boulder.

In general, the 1979 sediment percent comparisons among: (1) airphoto total area data for all 3 reaches, Table #2; (2) 8 cross-sections, both for airphoto and McCall ground data, Table #6; and (3) 20 transects in Krassel Hole and Poverty reach for airphoto and Boise ground data, Appendix 1, Table #3, are summarized in Table 21.

Table 21. Mean percentages of sediment types for all data types for 1979.

Data Types						
	Airphoto interpretation	8 cross-sections in 3 reaches			20 transects in 2 reaches	
Sediment (size)	of the 3 entire reaches	Airphoto data	McCall ground data	Sediment (size)	Airphoto data	Boise ground data
sand (<¼")	38	50.0	62	sand (<¼")	27	8
gravel (¼-4")	30	33.0	26	gravel (¼-4")	53	70
cobble (4-12")	17	13.0	11	rubble (4-12")	17	19
rubble (12-36")	11	2.5	1			
boulder (>36")	4	1.5	0	boulder (>12")	3	3

3.9 Summary of time and cost

The time and cost figures have been summarized in Table 22. The activities included in the preparation of the final maps are: sediment interpretation, area measurements, drafting of planimetric maps, and height measurements. It took 264 man-hours to examine, interpret, and map 92.98 hectares of stream channel area spread over the three reaches, Oxbow, Poverty, and Krassel Hole. The mapped area also includes Krassel Hole reach during 1946, 1947, and 1952. Cost of aerial photography, drafting materials and ground checking was not included in the above cost figures.

Total area interpreted/mapped	92.98 hectares
Total time spent	264 man-hours
Total cost	$1320.00
Cost/square m	$0.00142
Cost/hectare	$14.20
Time/hectare	2.84 hours

The cost of the airphoto technique versus the ground method for acquisition of data may be illustrated as follows. By using the remote sensing method, the production of a planimetric map of an area 100 square meters could be completed in 4-5 minutes and cost about one cent. In the ground sampling approach for the same segment of channel, mere collection of ground samples of sediments at one meter interval along this strip in a partly wet channel would consume five man-hours and cost about $25.00 total. The cost of access to the study area for ground sampling and cost of the aerial photography for photo interpreting have not been included for the sake of simplicity. This simple example clearly indicates the economy of time and effort involved in the two techniques. The economy is a fundamental justification for adopting the remote sensing technique in this project study.

Table 22. Summary of the cost ($) and time spent in producing planimetric maps depicting river bottom sediment types.

Activity	Reaches			Man-hours	Cost at $5/hr
	Krassel Hole	Poverty	Oxbow		
Interpretation	39	24	36	99	495
Area measurements	19	10	30	59	295
Drafting	30	20	21	71	355
Height measurements	15	10	10	35	175
Total	103	64	97	264	1320
Area mapped (m^2)	272,273	265,348	392,174	= 929,795 TOTAL	

4.0 Significance of Results

Remote sensing techniques using temporal large-scale colored air photographs were applied to detect and interpret streambed materials and changes in the channel cross-section. The interpretation was done stereoscopically using a Richards light table under high magnification. The sediments consisted of five categories. The results obtained from airphotos were compared visually, graphically and statistically with those of ground data.

A dichotomous interpretation key was developed for use in this study using previously collected field data and field checking procedures. The aerial photo data derived by using this key has been compared with the ground data. The average error of the photo interpretation was found to be within 10 percent of the McCall ground data. Repeated observations made in the modified design were compared and tested for any significant improvement in the aerial photo interpretation. The difference between the two sets was not found to be statistically significant. Therefore, it was inferred that the repeated observations were consistent and either set was equally good and suitable.

The same interpretation approach was applied to interpret the sediments on small scale air photos. Only broad categories could be detected and results generalized.

The results were presented in planimetric map form and time trend curves in graphical form using the PLOTALL computer program. The configuration of the channel was brought out in a contour map in the case of Krassel Hole reach. The ground and air photo observed elevations were tabulated and graphically compared as transect profiles for all eight cross-sections of the three reaches.

Statistical analysis was carried out using ground and airphoto sediment data. The results have been compared and discussed.

The two different techniques show substantial agreement in sediment distribution, elevations of river bed, and time trends. The means, standard deviations and multiple comparison tests show significant agreement between ground data and airphoto data.

The presentation of sediment data depicting spatial distribution and pattern of distribution over time using computer-aided designed maps rendered the final products within the bounds of comprehension.

Finally the study utilized the existing photographic documentation and enabled us to uncover the past history of this historic stream, the ideal abode of chinook salmon.

5.0 Discussion

In order to detect the riverbed sediments and study the time trends in the South Fork of the Salmon River, a threefold approach was followed. The first approach was based on the 12 planimetric maps prepared from the large scale colored airphotos. The maps, Figures 3 to 14, show the numerous changes that have taken place in the river channel at different periods of time. There was a decrease of sand at Krassel Hole between 1965 and 1972; thereafter, an increase from 1972-1979. This may have been due to a heavy rainfall in the South Fork watershed during 1975-76. Since 1976, gravel stabilized and sand has steadily increased. In Poverty reach, sand decreased at a significant rate between 1965 and 1972 with minor declines after that. Gravel decreased between 1972 and 1979. Rubble increased significantly between 1972 and 1979. The trend at Oxbow reach is similar to Krassel Hole; sand decreased at a faster rate between 1965 and 1972 and increased between 1972 and 1979. However, a breach occurred during 1975-76 at Oxbow causing a large decrease in sand and increase in gravel.

The second approach was based on data obtained by measuring the area of each sediment and plotting time trend curves on the computer, Figures 15 to 17, for all three reaches. At Krassel Hole sand decreased from 1965 to 1972, and increased between 1972 and 1979. Gravel decreased during the same period of time. The other sediments remained stable except for cobble which increased in 1972. In all probability, cobble was overestimated and gravel underestimated due to the use of one black and white large scale airphoto in 1972. A colored, large scale airphoto was not available and the gap was filled by including this photograph.

In the case of Poverty reach, sand gradually decreased from 1965 to 1979. Gravel increased from 1965 to 1972 and decreased at a steady rate to 1979. Cobble increased from 1972 to 1976 and decreased thereafter. Gravel, cobble, and rubble are the dominant categories at this reach at present.

At Oxbow reach the time trend curves show that sand decreased from 1965 to 1972 and increased from 1972 to 1976. Thereafter, it is quite steady. Gravel decreased from 1965 to 1972, did not change between 1972 and 1976, and increased significantly from 1976 to 1979. The other sediments remained unchanged.

The third approach was based on the statistical analysis, Tables 9 and 10. There is a significant difference in the distribution of sediments in the three sites in 1979. Poverty reach has more gravel while Krassel Hole and Oxbow have more sand. There were eight cross-sections selected over the three reaches. Analysis of variance showed that those cross-sections had different distributions of sediments among them. This further supported the above findings that the distribution of sediments was different at the three reaches.

Similar trends were noticed under the modified model. The analysis of variance based on airphoto data of ten transects at Krassel Hole reach, Tables 12 to 18, showed no significant variation in sand, while gravel decreased significantly over the period from 1965 to 1979. At the Poverty reach sand decreased significantly and gravel remained uniform from 1965 to 1979.

The time trends were also analyzed by producing computer maps using the modified design data. These maps proved very effective for discovering

changes, patterns and interpretation of the time trends. Changes in the sediment base over a period of time immediately became apparent from the computer maps.

The computer-produced maps highlighted the sediment movement in a very vivid manner. Interpretation of the sediment data was rendered an easy task when all four maps covering the period from 1965 to 1979 were viewed together. Even the statistically insignificant variations were found to be discernible and showed up in the individual maps. Gravel and sand were found to have mutual reciprocity. Where sand was transported, gravel was uncovered. Rubble and boulder were found to be stable in composition and remained relatively undisturbed over time.

The computer maps also compared the ground data and airphoto data. The overall agreement between airphoto data computer maps and ground data computer maps was found to be very good. The depiction of time trends in the riverbed sediments by computer-aided maps seemed to be a very effective visual presentation of data.

The river channel has undergone changes, sometimes very significant changes over time in its sediment distribution. As per the transects airphoto data, sand has been decreasing and gravel has been increasing from 1965 to 1979 at the Poverty reach. Gravel increased at Oxbow reach from 1976 to 1979 while sand remained steady. At Krassel Hole reach, sand continues to be the dominant sediment type while gravel has decreased.

The trends and mean sediment distribution varies according to the manner in which the data was collected. Referring back to Table 21 one can see a fair correlation in means for both airphoto and McCall ground data for 8 cross-sections and separately for airphoto and Boise ground data for 20 transects. But there is quite a difference in the means,

especially for sand and gravel, among the three different ways the data was collected, i.e., by a complete population measurement through airphoto interpretation, by sampling using 8 cross-sections among the three reaches, or by sampling using 20 transects for two reaches. The complete enumeration should provide better data and also maps showing the exact distribution of sediments within a segment of the river.

6.0 Conclusions and Recommendations

Remote Sensing techniques have successfully been employed in the interpretation and detection of time trends in the South Fork of the Salmon River. The airphotos under stereoscopic fusion provided the ability to see the entire surface of the riverbed and its sediments and to make a complete tally of the riverbed particles. The ground approach on the other hand is a sampling of transects or cross sections, unless an inordinate effort is made to map the entire bed. To its disadvantage, aerial photo interpretation can only map surface sediments.

It is recommended that only three sediment types--sand, gravel, and boulder--be considered for airphoto interpretation of salmon spawning sites. The size recommended for each of the categories is: sand--less than 0.25 inch, gravel from 0.25 inch to 6 inches and boulders greater than 6 inches. Gravel is the most preferred category for chinook salmon. These are also very convenient for interpretation from large scale aerial photos.

Based on experience in this study, a 1:2000 scale aerial photograph would be preferred in order to better determine sediment size class and measure height differences. The distinction between sand and gravel, especially where gravel was at the lower end of its size class and fairly homogeneous, was very subjective. In many cases this condition made gravel appear as sand and therefore classified as such.

Horizontal and vertical ground control would have been a valuable aid for contouring the riverbed channel on a stereoplotter and rectification of tilt in the photographs for making parallax measurements.

7.0 Problems Encountered

The large scale airphotos were burdened with excessive tilt. As a result all parallax measurements made from these airphotos were inflated with errors. Since the direction of tilt was unpredictable it was not possible to eliminate the tilt effect altogether. In case ground control is made available, then transparencies of these airphotos can be used on any stereoplotter and riverbed elevations could be measured and contour maps produced.

There were too many sediment categories. Sand, gravel, and boulders would have been more convenient for this technique. This will economize time and effort and improve interpretation accuracy. No valuable sediment information would be compromised.

Interpretation of a long stretch of the reach was suitable for broad understanding of the riverbed sediments. However, the sediment area percent derived from the planimetric maps lacked degrees of freedom and was not useful for statistical analysis. For statistical analysis the modified design using ten transects for interpretation with two sets of observations was found to be more effective and economical.

Computer maps were found to be a very effective visual presentation of time trends, but spatial relationships between transects and sediments were compromised in the process of these thematic maps. The sediment percent value was assigned to a single point on the transect and not to the whole transect and thus all ten transects were reduced to ten individual points in midstream.

Gravel in the dry part of the channel was found to have a very high reflectance and appeared as a very bright smooth tone on the airphotos leading one to believe it was sand. This can lead to overestimation of

sand and underestimation of gravel. Larger scale (1:2000) airphotos would help in a better interpretation of this problem. The taking of the photos during higher water periods may also help.

The extrapolation of large scale airphoto results to small scale airphoto results was done for a two-year overlap period and was reasonably good but only in broad categories of sediments. The technique can be used given a certain understandable error range.

Running water caused specular reflections on many areas of the stream and the bright spots interfered with interpretation of the sediments. Stereo interpretation can be used to alleviate this problem somewhat.

8.0 Literature Cited and Other Useful References

Amidon, E.L., D.A. Sharpnack, and R.M. Russell. 1971. The development of an earth resources information system using aerial photography and digital computers. Univ. of Calif., Remote Sensing Lab., Berkeley. Pp. 32-39.

American Society of Photogrammetry. 1979. Manual of remote sensing. Chapter V, Pp. 284-285.

American Society of Photogrammetry. 1968. Manual of color aerial photography. Chapter X, Pp. 405-406.

American Society of Photogrammetry. 1966. Manual of photogrammetry. Third edition. Chapter XII, Pp. 535-600.

American Society of Photogrammetry. 1966. Manual of photographic interpretation. Remote Sensing. Chapter I, Pp. 30-35.

Anderson, H.W. 1949. Flood frequencies and sediments from forested watersheds. American Geophys. Union Trans. 30:567-584.

Anderson, H.W. 1954. Suspended sediment discharge as related to stream flow, topography, soil, and landuse. Amer. Geophys. Union Trans. 35:268-281.

Anderson, H.W., and H.W. Trobitz. 1949. Influence of some watershed variables on a major flood. J. Forestry 47:347-356.

Andre, J.E., and H.W. Anderson. 1961. Variation of soil erodibility with geology, geographic zone, elevation and vegetation type in Northern California wildlands. J. of Geophys. Res. Vol. 66, Pp. 3351-3358.

Arnold, J.F. and L. Lundeen. 1968. South fork of the Salmon River special survey--soils and hydrology. Unpublished Report, Intermountain Region, USFS, Ogden, Utah. Pp. 16-21.

Ashe, W.W. 1907. Relationship of soil and forest cover to quality and quantity of surface water in the Potomac Basin. U.S. Geol. Sur. Water Supply Paper 192:299-335.

Avery, T.E. 1977. Interpretation of Aerial Photographs. Burgess Publishing Company, Minneapolis, Minnesota. Pp. 42-45.

Belchar, D.J. 1948. Determination of soil conditions from aerial photographs. Photogrammetric Eng., Vol. 14, Pp. 482-488.

Bernath, H.J. 1974. Integration of remote sensing and photogrammetry: A unified digital approach to interpretation and mapping of multispectral aerial photography. Univ. Wash., Dept. Civil Eng., Seattle. Pp. 11-32.

Bird, T., B.J. Meyer, and D.A. Ratkowsky. 1978. Recognition of patterns of damage in tall forests in Australia. CSIRO Div. of For. Res., Airport, Hobart, Australia. Pp. 4-9.

Bjornn, T.C., M.A. Brusven, and M.P. Molnau. 1980. Transport of granitic sediment in streams and its effects on insects and fish. Res. Tech. Comp. Rep. Proj. B-036-IDA. July 1974-July 1976. Submitted to Office of Water Res. and Tech. U.S. Dept. of Int., Wash., D.C. Pp. 11-42.

Black, R.F., 1952. Polygonal patterns and ground conditions from aerial photographs. Photogrammetric Eng., Vol. 18:123-134.

Bobek, H. 1941. The effects of erosion and denudation in various climates. Luftbild U. Luftbildmessung, No. 20. Pp. 38-71.

Burgess, L.C.N. 1970. The application of airphoto interpretation to watershed planning and development with special references to flood susceptibility and frequency determinations. Vol. 1 - text, Vol. 2 - illus.

Burns, J.W. 1972. Some effects of logging and associated road construction on north California streams. Trans. Amer. Fish. Soc. 101(1):1-17.

Cameron, H.L. 1952. The measurement of water current velocities by parallax methods. Photogrammetric Eng. 18(1):99-103.

Cedarholm, C.J., W.J. Scarlett, and E.O. Salo. 1977. Salmonid spawning gravel composition data summary from the Clearwater River and its tributaries. Jefferson County, Washington, 1972-76. Univ. Wash. Fish Res. Inst. Circ. 77-1. 135 pp.

Civco, D.L., W.C. Kennard, and M.W. Lefor. 1978. A technique for evaluating inland wetland photointerpretation: The cell analytical method (CAM). Photogrammetric Eng. and Remote Sensing, 44(8):1045-1052.

Cline, R.G., W.F. Megahan, R. Patton, and J. Potyondy. 1980. Guidelines for predicting sediment yields. USDA For. Serv. North. Reg. and Inter. Reg. Ogden, Ut. 48 pp.

Cole, G., and W.F. Megahan. 1980. South Fork Salmon River--future management. In Proc. Symp. on Watershed Manage. Vol. 1. Amer. Society of Civil Eng. Boise, Idaho. July 21-23, 1980. Pp. 396-405.

Coleman, C.G. 1960. Recent trends in photographic interpretation. Photogrammetric Eng. 26:755-763.

Colwell, R.N. 1964. Aerial photography--a valuable sensor for the scientist. Amer. Sci. 52:17-49.

Colner, B.J. 1966. Aerial photography in the Unified Information system. Highway Res. Record/Coden: Hirr-A/no. 142. U.S. Bureau of Public Roads, p. 16.

Cordone, A.J., and D.W. Kelley. 1961. The influence of inorganic sediment on aquatic life of streams. Calif. Fish and Game 47(2):189-228.

Cuplin, P. 1978. Remote sensing streams. In: Proceedings of Workshop on Integrated Inventories of Renewable Natural Resources. General Technical Report RM-55. Rocky Mountain Forest and Range Exp. Sta. Pp. 257-259.

Cuplin, P. 1978. The use of large scale color infrared photography for stream habitat inventory. Technical Note 425. USDI-BLM, Federal Center, Denver, Colorado. 7 pp.

Davis, V.M. 1974. Georgia computer mapping program. American congress on surveying and mapping. Proc. Fall Conv., Washington, D.C. Pp. 74-105.

Donald, J.B., E.H. Earnest. 1967. Potential benefits to be derived from applications of remote sensing of agriculture. For. and Range Res. Cornell Univ., Ithaca, N.Y. Pp. 180-189.

Dolan, R., and L. Vincnet. 1973. Coastal processes. Photogrammetric Eng. 39(2):255-260.

Drackett, K., T.W.D. Gregg, and J. Bale. 1975. Practical applications of low, medium and high altitude aircraft remote sensing data to landuse planning. Remote Sensing of Earth Res. Conf., 4th Annu. Tullahoma, Tn. Pp. 44-47.

Drishchl, H.J., D.L. Dabbs, and G.C. Gentle. 1975. Landscape classification and plant successional trends. Peace Athabasca Can. Wldlf. Serv. Rept. Ser. No. 30. Can. Wldlf. Serv., Place Vincent Massey, Hull, Que.

Eardley, A.J. 1941. Aerial photographs: Their use and interpretation. Harper and Brothers. 203 pp.

Genderen, J.A. 1977. Testing land-use map accuracy photography. Photogrammetric Eng. and Remote Sensing. 43(9):1135-1137.

Gilbert, W.F. 1978. Manual of practice, a reference handbook and training supplement for the statewide aerial surveillance program. State Water Resources Control Board. Div. of Planning and Res. Sacramento, Ca. Pp. 5-29.

Greentree, W.J. and R.C. Aldrich. 1976. Evaluating stream trout habitat on large scale aerial color photographs. Research paper PSW-123. Pac. S.W. Forest and Range Exp. Sta., USDA-FS, Berkeley, California. 21 pp.

Hart, C.A. 1940. Scientific interpretation of airphotos and their economic applications. London, Longmans, Green and Co. Pp. 74-89.

Hennigar, H.F. 1980. Quantification of changes in coastal topography using simple parallax measurements. Photogrammetric Eng. and Remote Sensing 46(1):71-75.

Hills, G.A. 1950. The use of aerial photography in mapping soil sites. Forestry Chronicle. 26(1):4-37.

Hosier, P.E., and W.J. Cleary. 1977. Cyclic geomorphic patterns of washover on a barrier island in southeastern North Carolina. Environ. Geol. 2:23-31.

Hultquist, M.B., G. Rushton, and R.P. Schmitt. 1971. Identifying and forecasting change in a regional system of urban places. Univ. of Iowa, Iowa City. Pp. 12-14.

Hunter, J.W. 1973. A discussion of game fish in the state of Washington as related to water requirements. Rep. by Fish Manage. Div. Wash. State Dept. Game to Wash. State Dept. Ecol. Olympia, Wa. 66 p.

Istvan, L.B. 1976. Landuse data interpretation from aerial photography for input to the section 208 water quality management program of the Toledo Metropolitan area council of governments. Ann Arbor, Mi. Pp. 51-55.

Johnson, E.W. 1958. Effects of photographic scale on precision of individual tree height measurements. Photogrammetric Eng. 24(1):142-152.

Johnson, P.L. 1966. A consideration of methodology in photo interpretation. U.S. Army Cold Regions Res. and Eng. Lab., Univ. Michigan. Pp. 17.

Kraft, C.L., and A.R. Yeslin. 1960. Detection of change in pictoral reconnaissance data. The Boeing Co., Seattle, Wa. Pp. 28.

Langfelder, J., D. Stafford, and M. Amein. 1968. A reconnaissance of coastal erosion in North Carolina. Dept. of Civil Eng., N.C. State Univ., Raleigh. Pp. 16-17.

Lewis, A.J., P.B. Larimore, and S.T. Kim. 1978. Computer mapping of wet-land soils using color infrared photography. F. Shahrokhi, ed. Univ. Tenn., Space Institute. Louisiana State Univ., Baton Rouge. Pp. 30-33.

Lyell, Sir Charles. 1849. A second visit to the United States of America. Vol. 1. London. Pp. 368.

MacConnell, W. and W. Niedwiedz. 1979. Remote sensing the White River in Vermont. Photogrammetric Eng. and Remote Sensing 45(10):1393-1399.

Malia, W.A. 1972. Information extraction techniques for multispectral scanner data. Lyndon B. Johnson Space Center (NASA), Houston, Tx. Pp. 123.

May, G.A., and G.W. Peterson. 1975. Spectral signature selection for mapping unvegetated soils. Library of Congress. Technical Information Division, Washington.

McKim, H.L., C.J. Merry, and E.A. Blackey. 1978. Use of remote sensing to quantify construction material and define geologic lineaments Dickey-Lincoln Schoollakes project, Maine. 12th Symposium on Remote Sensing of Environment Proc. 2:1027-1035.

Megahan, W.J., and W.J. Kidd. 1972. Effects of logging and logging roads on erosion and sediment deposition from steep terrain. J. of Forestry. 80:136-141.

Megahan, W.J., W.J. Kidd. 1972. Effects of logging roads on sediment production rates in the Idaho batholith. USDA For. Serv. Res. Pap. Int. 123. Pp. 120-121.

Megahan, W.F. 1975. Sedimentation in relation to logging activities in the mountains of Idaho. In Present and Perspective Technology for Predicting Sediment Yields and Sources. Proc. Sediment Yield Workshop. USDA Sedimentation. Oxford, Mass. Pp. 74-82.

Megahan, W.F., W.S. Platts, and B. Kulesza. 1980. Riverbed improves over time: South Fork Salmon River. Symposium, Watershed Management, Vol. 1. American Society of Civil Engineering, New York. Pp. 32-33.

Megahan, W.F., and A.M. Chima. 1980. Watershed management in Pakistan--Present, past, and future. J. For. 78(4):217-219.

Milfred, C.J., and R.W. Kiefer. 1976. Analysis of soil variability with repetitive aerial photography. Soil Sci. Soc. of America J. 40(4):553-557.

Mintzer, O.W. 1968. Photointerpretation of soils using color: Manual of color aerial photography. ASP--Falls Church, Va. Pp. 122-125.

Moessner, K.E. 1950. Principal uses of airphotos by the Forest Service. Photogrammetric Eng. 16:301-304.

Mollard, J.D. 1970. Photo interpretation studies in the location of prairie groundwater supplies. Canadian Geotech. J. 7(2):127-135.

Murtha, P.A. 1980. Modelling tree damage--type patterns for photo interpretation of SO2 injury. Int. Soc. Photo., 14th Congr. Hamburg, W. Germany. Pp. 17.

Ometodov, D. Izucheniia Gruntovyhk vod. 1969. Moscow-Linigard, USSR. Interpretation of ground water of typical landscapes in the Caspian low land on aerial photographs. Library of Congress, Technical Information Division, Washington.

O'Neil, C.P., J.E. Desteiquer, and G.W. North. 1978. Trend analysis of vegetation in Louisiana's Atchafalaya River basin. William T. Pecora Mem. Symp., Appl. of Remote Sensing Data to Wldlf. Mgmt. Proc. 4th. Sioux Falls, S.D. Pp. 114-136.

Parvis, M. 1946. Development of drainage maps from aerial photographs. Proc. Nat. Res. Council, Highway Res. Board, 26:151-163.

Platts, W.S., and W.F. Megahan. 1975. Time trends in riverbed sediment composition in salmon and steelhead spawning areas: South Fork Salmon River, Idaho. Trans. 40th N. Am. Wldlf. Conf. Wldlf. Mgmt. Inst.

Polcyn, F.C. 1978. Data analysis techniques. U.S. NASA, Scientific and Technology Information Office, Washington, D.C. Pp. 87-88.

Pope, R.B. 1960. Ocular estimation of crown density on aerial photos. Forestry Chronicle 36(1):89-90.

Putnam, W.C. 1945. Photo interpretation. Pitman Publ. Co., New York. Pp. 332-353.

Reiser, D.W., and T.A. Wesche. 1977. Determination of physical and hydraulic preferences of brown and brook trout in the selection of spawning locations. Wyo. Water Res. Inst., Laramie. Ser. No. 64. p. 100.

Roscoe, B., Herrington, and S.R. Tocher. 1967. Aerial photo techniques for a recreation inventory of mountain lakes and streams. Inter. For. and Range Exp. Sta., For. Serv., USDA, Ogden, Ut. Pp. 6-8.

SAS Institute. 1979. Statistical analysis system user's guide. 1979 edition. Box 8000, Cary, North Carolina 27511. Pp. 121-130 and 237-244.

Scarpace, F.L. 1975. Quantitative photointerpretation for wetland mapping. American Society for Photogrammetry. 4th Annu. Proc., Falls Church, Va. Inst. of Environ. Studies, Univ. of Wisconsin, Madison. Pp. 22

Schmer, F.A., R.E. Isakson, and J.E. Eidenshink. 1977. Investigation of remote sensing techniques as inputs to operational resource management. Goddard Space Flight Center (NASA), Greenbelt, Md. Pp. 57-59.

Schmidt-Falkenberg, H. 1974. Experimental reserach on some methods of photo-interpretation. Symposium on Remote Sensing Proc. Banff, Alta. Intern. Soc. for Photo. Pp. 122-124.

Shay, J.R. 1970. Remote sensing with special reference to agriculture and forestry. U.S. Nat'l. Acad. of Sci. 424 pp.

Shephard, F.P. 1950. Photography related to investigation of shore processes. Photogrammetric Eng. 16:756-769.

Shipley, B.L. 1980. Remote sensing for detection and monitoring of salt stress on vegetation: Evaluation and guidelines. Library of Congress. Technical Information Division, Washington. Pp. 64-68.

Sonu, C.J. 1964. Study of shore processes with aid of aerial photogrammetry. Photogrammetric Eng. 30(6):932-941.

Sprules, W.M. 1947. An ecological investigation of stream insects in Algonquin Park, Ontario. Univ. Toronto. J. of Biol. 69:1-81.

Stafford, D.B., J.T. Ligon, and M.E. Nettles. 1973. Utilization of aerial photographs for measuring land use changes in watersheds, remote sensing and water resources management. Am. Water Res. Assoc. Proc. No. 17. Pp. 312-324.

Steiner, D. 1973. Technical aspects of air photographic interpretation in the USSR. Photogrammetric. Eng. 29:988-997.

Stellingwerf, D.A. 1979. Orthophoto maps and/or LANDSAT print-outs for forestry: Aspects of a quantification problem. Proc. of Remote Sensing for Natural Resources. Univ. of Idaho. Pp. 424-441.

Stobbs, A.R. 1968. Some problems of measuring land use in underdeveloped countries: The land use survey of Malawi. Cartographic J. 5:107-110.

Strandberg, C.H. 1967. Aerial discovery manual. John Wiley and Sons. Pp. 24-31.

Striffer, W.D. 1964. Sediment stream flow and land use relationships in northern lower Michigan. Lake States For. Exp. Sta., USFS, Dept. of Agri. Res. Pap. LS-16. Pp. 30-34.

Tanner, W.F. (ed.). 1978. Standards for measuring shoreline changes. Coastal Research and Dept. of Geology. Fla. St. Univ., Talahassee. p. 87.

Tappel, P.D., and T.C. Bjornn. 1980. Effects of sediment composition on salmonid egg survival. Annu. Rept. for the period Sept. 1979 - Oct. 1980. Inter. For. and Range Exp. Sta., U.S. For. Serv. Pp. 43.

Thomas, R.W. 1974. Remote sensing-aided procedures for water yield estimation. An integrated study of earth resources in the State of California using remote sensing techniques. Semi-annual Prog. Rept. Univ. of California, Berkeley. Pp. 152.

Ulliman, J.J., E.O. Garton, and J.A. Keay. 1979. Wildlife habitat classification using large scale aerial photography. Proc. For. Res. Inv. Wkshp, Colorado St. Univ., Fort Collins. Pp. 414-422.

Wanless, H.R., and M.T. El-Ashry. 1968. Photo-interpretation of shoreline changes between Cape Hatteras and Fear, N.C. Marine Geology. Vol. 6. Pp. 75-76.

Watson, R.D., and R.J. Hoyle, Jr. 1975. Remote sensing in Idaho. Idaho Agri. Exp. Sta. Bull. 23 pp.

Weiser, D.W., and T.C. Bjornn. 1979. Influence of forest and rangeland management on anadromous fish habitat. USDA For. Serv. Anadramous Fish Habitat Program. Pac. NW For. and Range Exp. Sta. Gen. Tech. Rept. PNW-96. Pp. 35.

Zeigler, J.M., and F.C. Ronne. 1957. Time lapse photography--An aid to studies of the shoreline. Naval Res. Rev. ONR.

Zonneveld, I.S. 1974. Aerial photography, remote sensing, and ecology. ITC Journal. Enschede, Netherlands. 4:553-560.

9.0 Appendix 1

Table 1. 1965 sediment percentages at 10 transects (modified model).

Year--1965											
Krassel Hole Site						Poverty Site					
Transect Number	Sand	Gravel	Rubble	Boulder	Remark	Transect Number	Sand	Gravel	Rubble	Boulder	Remark
1	50	40	10	0	No ground	1	29	63	8	0	No ground
	42	48	8	2	data		37	60	3	0	data
	--	--	--	--	available for 1965		--	--	--	--	available for 1965
2	46	32	16	6		2	36	58	6	0	
	48	39	10	3		2	41	55	4	0	
	--	--	--	--			--	--	--	--	
3	50	28	16	6			56	40	4	0	
	44	37	16	3		3	46	50	4	0	
	--	--	--	--			--	--	--	--	
4	38	35	22	5			34	43	23	0	
	47	38	12	3		4	33	56	8	3	
	--	--	--	--			--	--	--	--	
5	45	32	16	7			21	41	37	1	
	43	42	14	1		5	22	38	38	2	
	--	--	--	--			--	--	--	--	
6	50	45	5	0		6	30	32	22	16	
	47	53	0	0			30	37	20	13	
	--	--	--	--			--	--	--	--	
7	52	43	5	0			44	48	8	0	
	55	42	3	0		7	40	48	12	0	
	--	--	--	--			--	--	--	--	
8	46	36	18	0		8	22	39	35	4	
	49	41	10	0			26	47	26	1	
	--	--	--	--			--	--	--	--	
9	30	67	3	0			0	50	47	3	
	33	59	8	0			11	57	27	4	
	--	--	--	--			--	--	--	--	
10	56	22	22	0		10	0	50	40	10	
	47	32	21	0			0	40	50	10	
	--	--	--	--			--	--	--	--	

9.0 Appendix 1

Table 2. 1972 sediment percentages at 10 transects (modified model).

Year--1972											
	Krassel Hole Site					Poverty Site					
Transect Number	Sand	Gravel	Rubble	Boulder	Remark	Transect Number	Sand	Gravel	Rubble	Boulder	Remark
1	29	57	9	5	1st set	1	37	55	8	0	1st set
	26	54	16	4	2nd set		33	60	7	0	2nd set
	27	56	8	9	ground data		47	53	0	0	ground data
2	35	54	7	4		2	39	54	7	0	
	40	43	13	4			33	60	7	0	
	13	77	8	2			56	36	8	0	
3	40	50	7	3		3	29	65	6	0	
	68	22	8	3			30	64	6	0	
	22	63	8	7			21	71	8	0	
4	52	40	5	3		4	10	60	30	0	
	68	22	7	3			20	50	30	0	
	13	81	3	3			16	42	42	0	
5	42	49	6	3		5	10	60	30	0	
	67	22	9	2			20	50	30	0	
	11	75	9	5			9	61	30	0	
6	43	51	4	2		6	26	54	20	0	
	45	38	13	2			25	60	15	0	
	25	69	2	3			38	37	25	0	
7	27	68	3	2		7	21	54	23	2	
	33	41	24	2			25	60	15	0	
	17	71	11	1			25	65	8	2	
8	36	64	0	0		8	9	69	19	3	
	33	53	11	3			11	42	38	9	
	15	77	8	0			20	66	14	0	
9	30	66	4	0		9	0	62	34	4	
	33	56	8	3			11	42	38	9	
	23	42	24	11			5	40	53	2	
10	36	61	3	0		10	0	40	50	10	
	20	60	20	0			0	20	60	20	
	38	28	29	5			2	29	62	7	

9.0 Appendix 1

Table 3. 1976 sediment percentages at 10 transects (modified model).

Year--1976											
Krassel Hole Site						Poverty Site					
Transect Number	Sand	Gravel	Rubble	Boulder	Remark	Transect Number	Sand	Gravel	Rubble	Boulder	Remark
1	25	47	14	14	1st set	1	54	46	0	0	1st set
	29	39	23	9	2nd set		45	55	0	0	2nd set
	11	18	66	5	ground data		45	55	0	0	ground data
2	55	17	14	14		2	17	74	9	0	
	33	38	20	9			20	80	0	0	
	9	66	16	9			37	63	0	0	
3	55	20	13	12		3	24	68	8	0	
	33	38	20	9			27	51	17	0	
	6	59	25	9			12	81	7	0	
4	55	20	13	12		4	30	65	5	0	
	50	25	14	11			40	60	0	0	
	12	63	18	7			7	76	17	0	
5	50	16	18	16		5	26	67	7	0	
	50	25	13	12			30	60	10	0	
	5	81	9	5			14	83	3	0	
6	50	45	5	0		6	25	69	3	3	
	43	45	8	4			25	62	13	0	
	8	68	18	6			8	86	2	4	
7	44	48	8	0		7	20	80	0	0	
	43	45	8	4			30	70	0	0	
	8	65	25	2			8	81	11	0	
8	26	62	12	0		8	11	71	13	5	
	35	45	18	2			19	63	18	0	
	6	89	4	1			9	40	50	1	
9	46	49	5	0		9	13	56	30	1	
	40	42	18	0			21	55	18	6	
	18	63	16	3			1	15	79	5	
10	37	56	7	0		10	10	20	70	0	
	51	43	6	0			13	20	60	7	
	8	51	41	0			10	8	78	4	

9.0 Appendix 1

Table 4. 1979 sediment percentages at 10 transects (modified model).

Year--1979											
Krassel Hole Site						Poverty Site					
Transect Number	Sand	Gravel	Rubble	Boulder	Remark	Transect Number	Sand	Gravel	Rubble	Boulder	Remark
1	40	44	10	6	1st set	1	28	65	7	0	1st set
	44	42	9	5	2nd set		27	60	13	0	2nd set
	3	74	12	11	ground data		20	80	0	0	ground data
2	40	44	10	6		2	22	50	25	3	
	44	42	9	5			28	57	14	1	
	2	70	26	2			46	50	1	3	
3	41	43	9	7		3	24	76	0	0	
	40	42	12	6			18	72	10	0	
	3	80	8	9			7	83	10	0	
4	53	35	8	4		4	15	80	5	0	
	42	38	13	7			10	70	20	0	
	3	84	5	8			4	78	18	0	
5	51	36	9	4		5	14	81	5	0	
	49	37	9	5			15	71	14	0	
	6	68	17	9			5	85	8	2	
6	51	38	9	2		6	30	48	12	10	
	49	43	5	3			24	69	6	1	
	10	82	6	2			6	80	10	4	
7	38	48	5	9		7	18	77	5	0	
	48	44	5	3			10	80	10	0	
	4	92	2	2			6	92	2	0	
8	33	48	13	6		8	6	62	26	6	
	43	40	15	2			5	65	25	5	
	17	73	8	2			4	59	34	3	
9	52	43	5	0		9	0	25	64	18	
	42	47	11	0			2	30	52	16	
	3	66	26	5			0	20	79	1	
10	46	44	8	10		10	0	20	70	10	
	35	46	16	3			0	20	70	10	
	1	52	44	3			4	26	67	3	

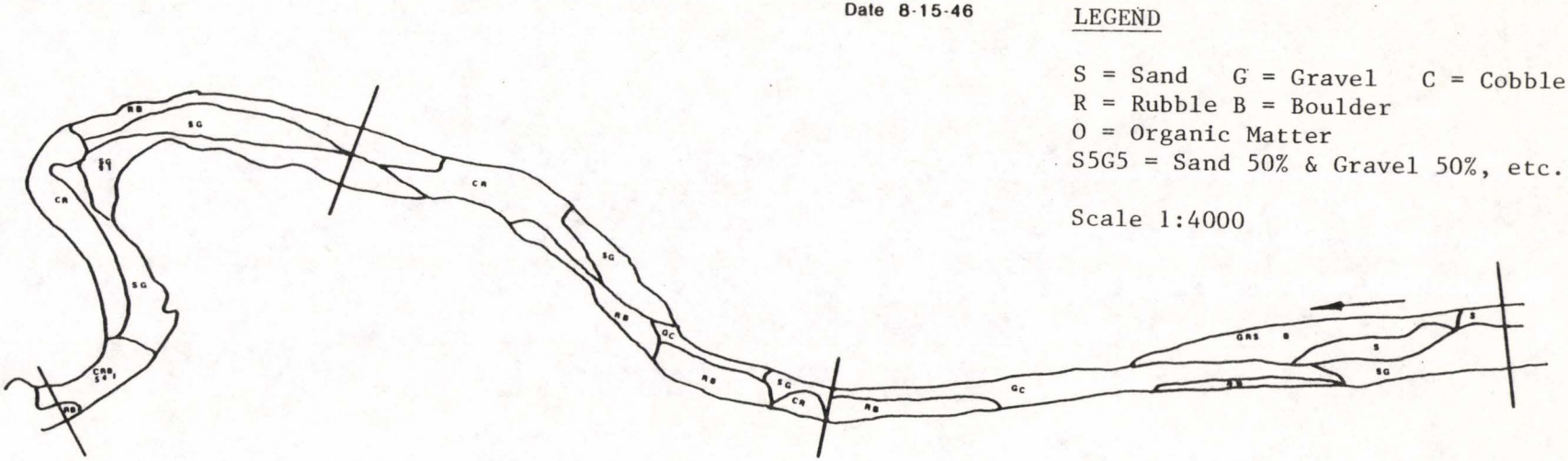


Figure 1. Planimetric map of 1946 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.

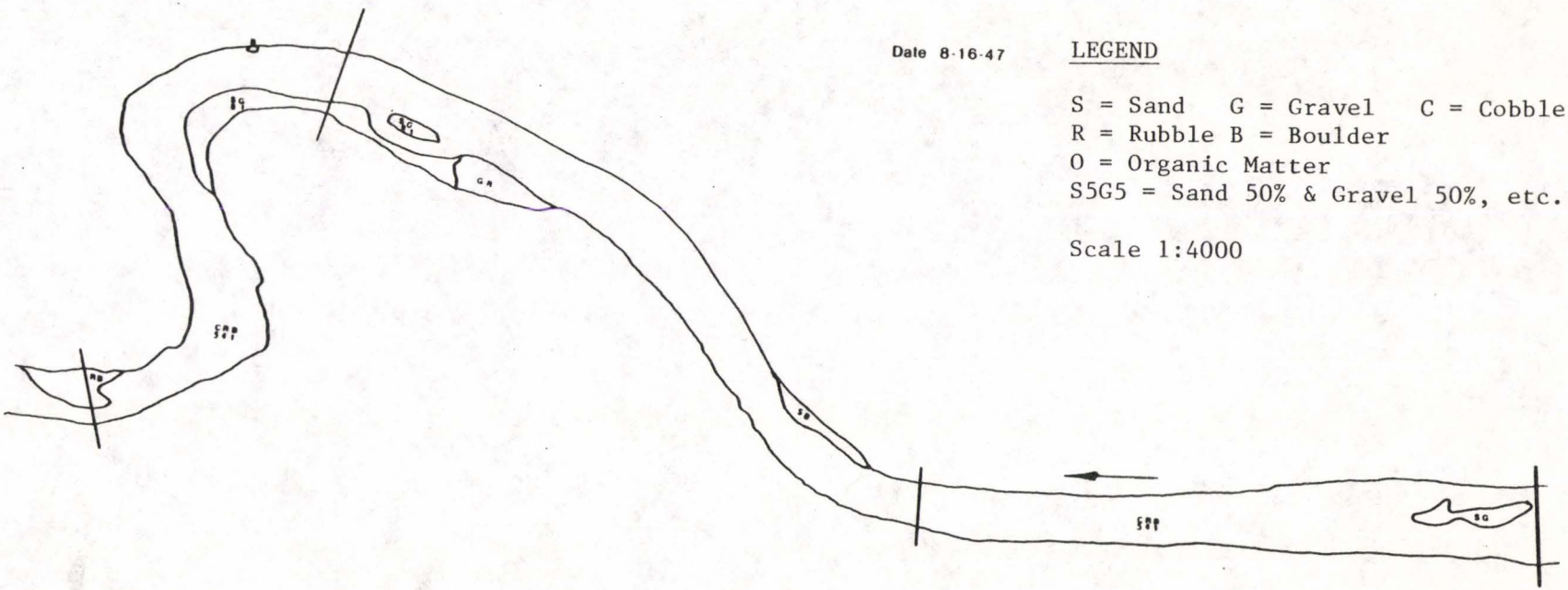


Figure 2. Planimetric map of 1947 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.

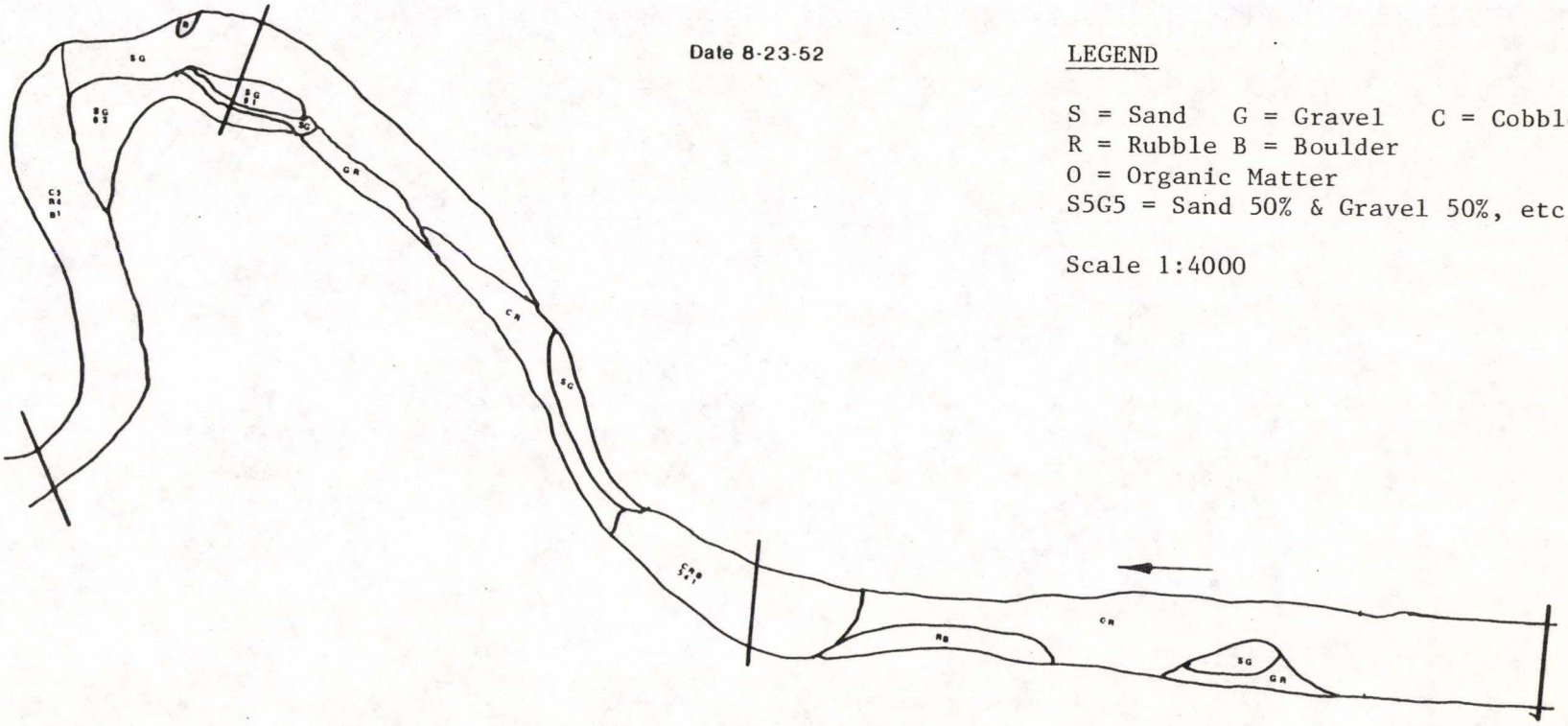


Figure 3. Planimetric map of 1952 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.

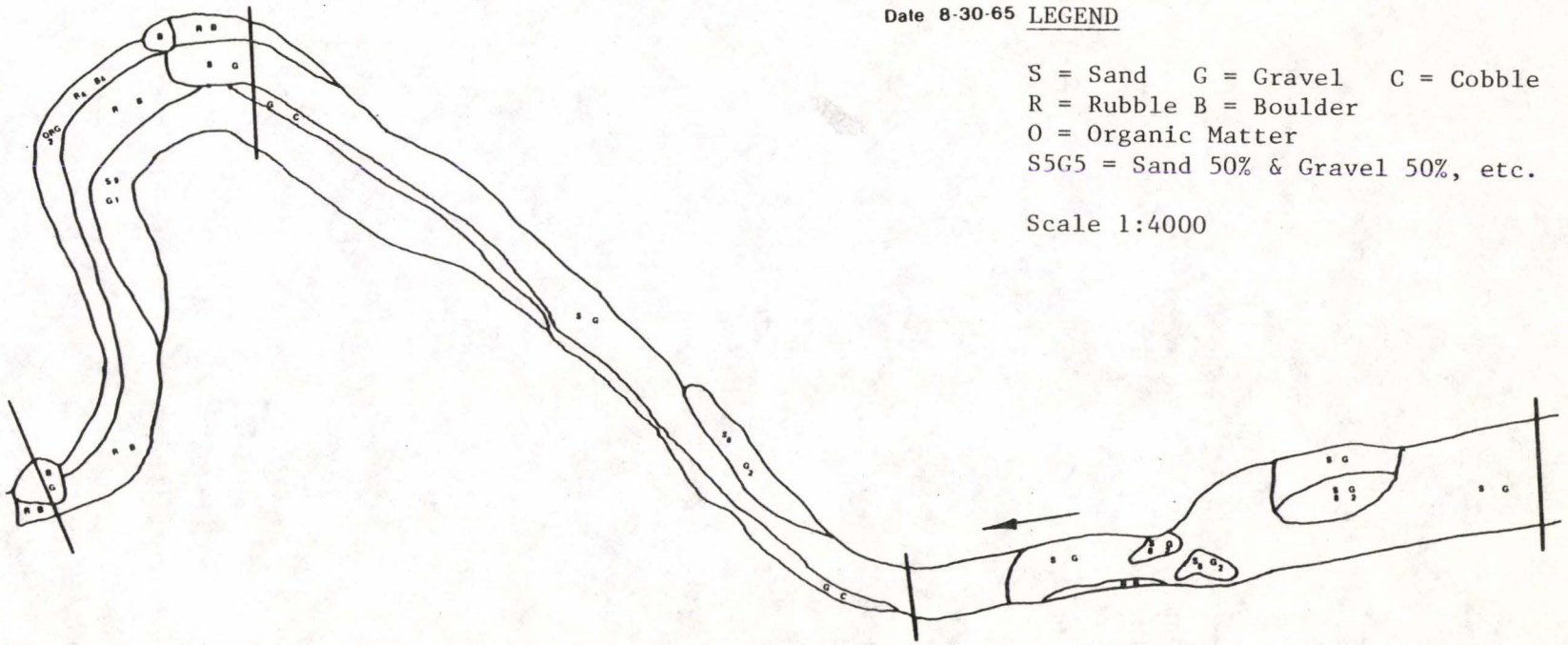


Figure 4. Planimetric map of 1965 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.

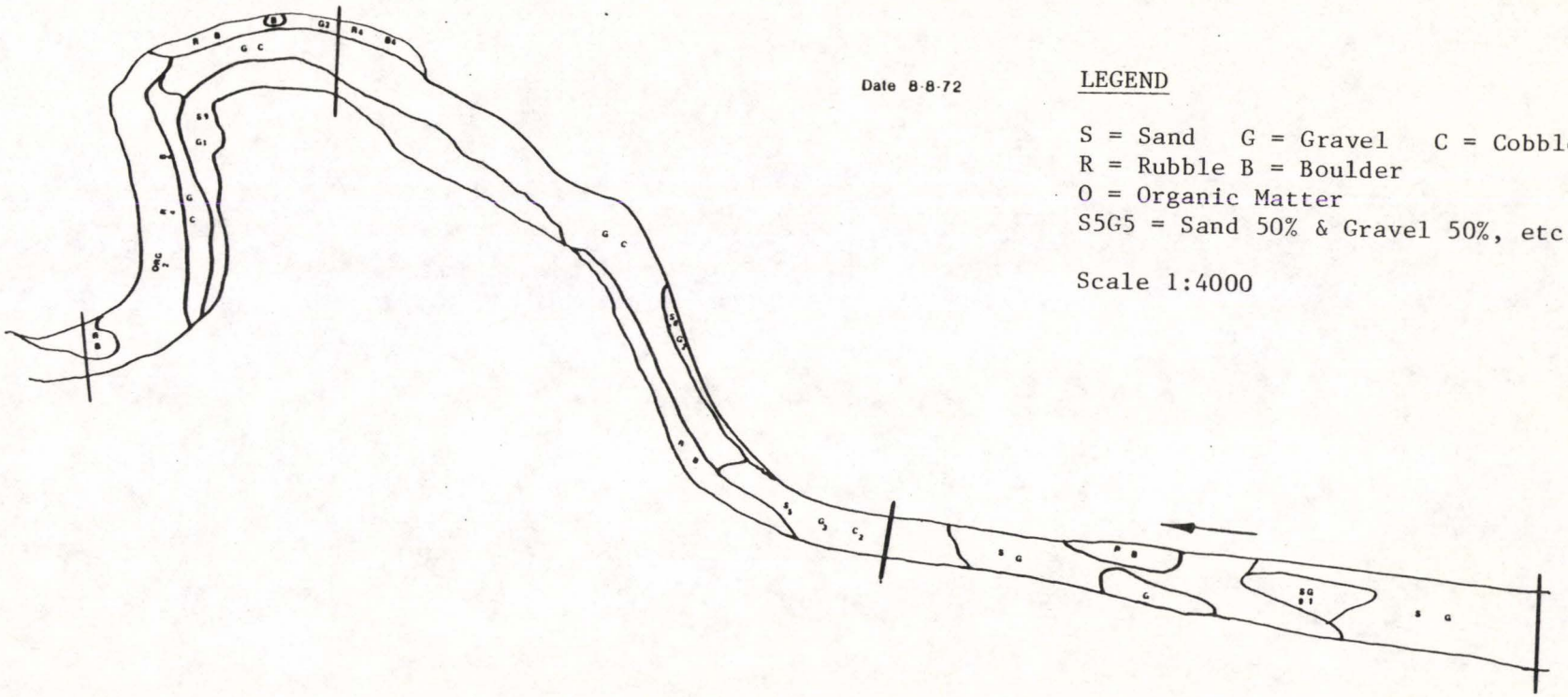


Figure 5. Planimetric map of 1972 riverbed sediments at Krassel Hole reach, based on interpretation of small scale airphotos.